

Campus de l'Université de Montréal
C.P. 6128, succursale Centre-ville
Montréal QC H3C 3J7 Canada

Telephone (514) 343 7575
Télécopieur (514) 343 7121

crt@crt.umontreal.ca
www.crt.umontreal.ca



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RISK HOMEOSTASIS RECONSIDERED

- The Limits of Traffic Safety Regulation -

by

Falk Kalus

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Falk Kalus¹

¹ Dresden University of Technology, Faculty of Economics and Business Management, 01062
Dresden, Federal Republic of Germany

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Abstract

Risk homeostasis theory (RHT) is a behavioral theory of risk relating to road traffic. Until today, most of the papers published concerning RHT are based on long time series and econometric methods which are not well adapted to the problem structure. Here we propose to address the issue by alternatively using the econometric concept of stationary and a concept based on dummy variables. We then test the RHT with German traffic accident data and specifically analyze compulsory traffic safety measures (the penalty for not using seat belts) as well as the effects of German reunification. Both do not have the effects as suggested by RHT. Our results, found by using several risk measures, show only weak evidence for RHT. Contrary to RHT, we can show that compulsory safety measures combined with penalties had a strict positive effect on road traffic accident risk. Furthermore, we develop a concept to better map the complex decision-making process of individual road-traffic risk within the context of theories that explaining individual's decision-making under uncertainty. We can show that these theoretical concepts are very well suited to explain the actual behavior of road users.

Key words: risk homeostasis theory, road traffic, behavior, decision making, time series, stationary, Germany

Zusammenfassung

Die Risikohomeostasistheorie (RHT) stellt ein formales Konzept zur Erklärung menschlichen Verhaltens im Straßenverkehr bei verändertem Unfallrisiko dar. Vor dem Hintergrund des gegenwärtigen Standes der Ökonometrie weisen die Untersuchungen zur RHT mittels langer Zeitreihen einige Schwächen auf. Im folgenden wird versucht, diese einerseits mit dem Stationaritätskonzept der Ökonometrie und andererseits mit einer auf Dummyvariablen basierenden Methode zu beheben. Gleichzeitig wird die Theorie einem neuerlichen Test auf ihre Gültigkeit hinsichtlich der Unfallsituation im Straßenverkehr in Deutschland unterzogen. Die Arbeit nimmt Bezug erstens auf die Wirksamkeit von Regulierungsmaßnahmen (hier: Verschärfung der Gurtanlegepflicht) und zweitens auf die Folgen der deutschen Wiedervereinigung. Für beide Ereignisse lassen sich die von der RHT unterstellten Wirkung nicht deutlich zeigen; die Ergebnisse der Analysen unterstützen die Thesen der RHT nur schwach. Sie belegen, daß konsequente und mit Strafandrohung belegte Regulierungsmaßnahmen entgegen dem Postulat der Risikohomeostasistheorie eine stark positive Wirkung auf die Unfallsituation ausüben. Weiterhin werden die komplexen Entscheidungsprozesse von Verkehrsteilnehmern im Kontext mehrerer theoretischer Konzepte untersucht. Es zeigt sich, daß Theorien zur Beschreibung individuellen Verhaltens unter Unsicherheit sehr gut geeignet sind, tatsächliches Verhalten von Verkehrsteilnehmern zu erklären.

Schlüsselbegriffe: Risikohomeostasistheorie, Straßenverkehr, Entscheidungstheorie, Zeitreihen, Stationarität, Deutschland

Résumé

La théorie de l'homéostasie du risque (RHT) est une théorie de comportement du risque en relation avec la sécurité routière. Jusqu'à présent, la plupart des articles publiés sur ce sujet utilisent des séries chronologiques et des méthodes économétriques qui ne sont pas bien adoptées à cette problématique. Dans ce papier, nous proposons une alternative basée sur le concept stationnaire et des variables dichotomiques. Par la suite, nous évaluons le RHT avec les données d'accidents de la route en provenance d'Allemagne en tenant compte des effets touchant la sécurité routière (comme, par exemple, les points d'inaptitude pour le non-port de la ceinture de sécurité), de même que des effets de la réunification de l'Allemagne. Ces mesures n'ont pas les effets escomptés par le RHT. Nos résultats ont montré que les mesures de risques sont faiblement associées au RHT, tandis que les mesures touchant la sécurité routière sont positivement reliées au risque d'accident. Nous avons également développé un concept afin de mieux concevoir le processus de la prise de décision du risque individuelle sous incertitude. Nous pouvons montrer que ces concepts théoriques conviennent bien pour expliquer le comportement des usagers de la route.

Mots clés : théorie de l'homéostasie du risque, sécurité routière, usagers, prise de décision, séries chronologiques, concept stationnaire, Allemagne

Preface

The economic analysis of transportation systems has been a central focus of research at the Chair of Economic Policy Analysis at the Dresden University of Technology. Within a context of a research network that included the *Centre de recherche sur les transports* of the *Université de Montréal*, a number of theoretical, methodological and empirical studies have been produced. Transportation demand and accident models, and the analysis of risk homeostasis among them, have been of special interest.

In the following, the author restates classical risk homeostasis theory and empirically tests it within the framework of German data from 1968 to the present. Important theoretical contributions include a PROPER definition of risk homeostasis that allows the concept to be subjected to falsification tests. It includes the distinction among risk homeostasis, in a narrow sense, for one type risk, risk substitution among different types of risks, and risk adaptation. Econometric models that analyze the stationarity of time series are used as the BASIS of the empirical analysis in which the compulsory belt usage and German Unity are used as exogenous shocks. The author claims that within this context, there exists no sound proof of risk homeostasis (in the narrow sense,) proper, but merely of risk substitution effects.

Beyond this analysis, the author questions the wisdom of the decision models that underlie classical risk analysis, especially expected utility theory, and HE claims that drivers simply are not able to properly include differentiated accident probabilities in their behavior. He proposes prospect theory and support theory as partial solutions to this problem.

This thesis is substantially widening our knowledge about risk homeostasis. Content and structure supply sufficient evidence that this type of analysis should not be limited to transportation alone; we hope for other scholars to apply the techniques to other fields in which risk and accidents play a dominant role, such as work security or sport and leisure activities.

Dresden and Montréal

Ulrich Blum

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Abbreviations

ABS	Anti Blocking System
ADF test	Augmented Dickey-Fuller test
BAST	Bundesanstalt für Straßenwesen (Federal Highway Research Institute)
BMV	Bundesministerium für Verkehr (Federal Ministry of Transport)
DIW	Deutsches Institut für Wirtschaftsforschung (German Institute of Economic Research)
IDW	Institut der deutschen Wirtschaft Köln (Cologne Institute for Business Research)
STBA	Statistisches Bundesamt (Federal Statistical Office Germany)
SZ	Süddeutsche Zeitung

Chapter 1

Introduction: Traffic Safety and the Effects of Exogenous Events

Traffic safety is a frequently debated problem in society. For the most part the accident risk is the subject of the discussion. Topics are manifolded, e. g., accident risks for children (SZ, February 7, 2001; WELT, August 4, 2000), drunk driving (WELT, March 18, 2000), and fatalities (SZ, February 22, 2001). Accident risks are frequently pronounced by accident statistics (see the literature just mentioned and WELT, November 24, 2000).

Of most interest to traffic safety are exogenous influences on the system. This particularly concerns new safety measures as well as further societal or political events, which may lead to a changing road traffic safety by changing traffic demand. As a first exogenous event we analyze the intensified seat belt legislation in Germany. It came into effect in August, 1984.¹ ADAMS (1994) stated that "seat belt legislation appears to have been one of the most effective safety measure ever devised" (p. 135). Despite this relevance of the seat belt to traffic safety the German experience in seat belt legislation is not yet investigated within a broad context. Not even RIVARA ET AL. (1999) mentioned a German study in their

¹ Due to this measure car occupants have to pay a penalty of DM 40, if they were unbelted. Meanwhile this penalty increased to DM 60.

review of 48 investigations of seat belt legislation. The second exogenous event considered is the German reunification in 1990. In East Germany traffic accident risks are substantially higher than in the West. For instance, in 1997 the fatality risk was 252 per 1 Million inhabitants in the federal state Brandenburg, East Germany, but only 104 per 1 Million inhabitants in all of Germany (COLDITZ, 1998). Our study considers both: a traffic safety measure or, more precisely, its intensification, as well as an outstanding societal event.

Various groups are interested in solutions improving traffic safety. First, the driving population is interested in lowering their accident risks in road traffic. In 1991 approximately 75% of the German population or more than 92% of the adults possessed a driver's license (DIW, 1998, pp. 105 and 127). Since traffic accidents cause enormous economic losses, e. g., 68 Billion DM in 1998 (BAST, 2000), the German state and, thus, the responsible road traffic planner might also be interested in lowering traffic accidents and their consequences. Finally, the car producing industry may want to raise the safety of the cars to achieve a higher acceptance for their products. In particular the interests of the latter two groups may include empirical evidence as well as theory-based predictions pointing to improvements in road traffic safety. The study below covers two things, first, an empirical analysis of (a) the effects of a traffic safety measure (intensified seat belt legislation) and (b) an outstanding societal event (German reunification) is given. Second, three theories explaining individual behavior and individual decision-making processes are discussed in light of the intensified seat belt legislation.

The importance of this domain on the public might be illustrated by one example about the causes of an accident. In 1995 the Ford Motor Company was sued for damages concerning a fatal accident in 1988 (WELT, September 21, 1995). A person was killed in a car which was not equipped with an airbag. This technology was already available, but Ford did not voluntarily equip all the cars with airbags. It was claimed by the prosecutor that Ford should have voluntarily equipped its cars with this system.

This case may clarify the problem and the actual discussion about safety mea-

asures and their effectiveness. One answer provides risk homeostasis theory, a frequently applied approach in this context. Whatever the result of the lawsuit is,² representatives of the risk homeostasis theory (WILDE, 1982a) would always question the effectiveness of such a safety measure. Even if the airbag prevents the fatality in this single case drivers generally compensate the resulting decrease in their accident risk. They take hazards in other driving situations or even in domains other than road traffic. For example, they may partake in free climbing, bungee jumping, or other dangerous sports. The concept of risk homeostasis, which will be discussed in more detail below, refers to an individual's attitude to risk. Following this theory any effort to lower accident risks is doomed to failure, because people react in a way resulting in a constant risk level.

Contrary to the predictions of risk homeostasis theory, data can be found supporting the notion that certain accident risks can effectively be decreased by introducing new safety measures. People do not completely compensate the gained increase in safety. Risk can effectively be reduced (see, e. g., EVANS, 1986a). In this study a solution is presented covering the deviating statements. We reconsider risk homeostasis in light of the intensified seat belt legislation as well as in light of German reunification.

We also develop a solution which focuses on the complex decision-making process of an individual. In light of the mentioned case concerning the not installed airbag, we may formulate a more detailed question: What decision processes are behind the reasons why the owner did not voluntarily equip his car with an airbag? The answer to this question is delivered by an investigation of human decision making processes under uncertainty. TVERSKY and KAHNEMAN (1974) mentioned "that the subjective probability of traffic accidents rises temporarily when one sees a car overturned by the side of the road" (p. 1127). Confronted with accident risk individuals have to judge the uncertain consequences as well as the advantages and the disadvantages of a traffic safety measure before they choose their driving behavior.

² Unfortunately, the result of the lawsuit was not published.

The analysis below goes as follows. In chapter 2 we review the concept of risk homeostasis and the various criticism. This serves as the basis for generating an adjusted interpretation of this theory concerning road traffic (see chapter 3). We limit homeostasis (a) to risk substitution effects and (b) to long-term risk adjustment effects. In chapter 4 we introduce the two examples of the empirical investigation of traffic accidents in Germany. These are (a) the intensified seat belt legislation in West Germany in August, 1984, and (b) German reunification in 1990. Based on the the reasoning relating these examples and the adjusted interpretation of risk homeostasis we deduce some hypotheses. In chapter 5 we present an econometric methodology based on a time series analysis, which is suitable to test these hypotheses. We analyze the underlying risk measures in two ways. First, the series are tested for equilibrium paths and structural breaks. Second, we estimate deviations from equilibrium paths after structural breaks are found. The results of the empirical analysis are described and interpreted in chapters 6 and 7. Because of the empirical findings, in chapter 8 we introduce three theoretical concepts describing individual behavior under uncertainty. In chapter 9 seat belt legislation is reconsidered within these three concepts by analyzing the decision-making processes of individuals. We draw some general conclusions concerning the effects of exogenous events in traffic safety. Finally, we refer to the chances of the regulations of traffic safety and their limits.

Chapter 2

Risk Homeostasis Theory

The concept of risk homeostasis refers to offsetting behavior of individuals when they are confronted with changes in risks to which they are exposed daily in their environment (WILDE, 1982a). Risk homeostasis is based on the theory of risk compensation by WILDE (1978).¹ It covers a wide variety of domains and, therefore, it is able to predict even complex risk adjustment processes. It is not limited to the domain of road traffic (WILDE, 1986b). Because of this global concept, the theory is frequently reconsidered, and it is applied to explain an individual's risk taking behavior (see, e. g., SMITH and LOVEGROVE, 1983; VELING, 1984; CHIRINKO and HARPER, 1993). Since the risk homeostasis theory is primarily formulated in road traffic a substantial discussion of this theory exists which is limited to this narrow domain. Below we review the theory of risk homeostasis and the criticism in literature. We start with an earlier concept which is similar to risk homeostasis and which might be interpreted as the foundation for the theory.

¹ A further discussion of the concept of risk homeostasis was given by WILDE (1982b; 1984; 1986a,b; 1988; 1989; 1994) and WILDE and KUNKEL (1984).

2.1 Risk Adjustment Among Various Road User Groups

The discussion about the effectiveness of safety measures in road traffic is based on a paper by PELTZMAN (1975). He questioned their effectiveness since negative effects primarily affect pedestrians and bicyclists rather than car occupants. Saved occupant's lives are obtained at the expense of a higher pedestrian fatality rate and an increasing accident rate.

PELTZMAN referred to a standard established during the 1960s in the U.S. which covers numerous regulations, like seat belts for all occupants, the dual braking system, and the energy-absorbing car interior. The measures do not change the private demand for safety, which is fixed (PELTZMAN, 1975, p. 682). Individuals have a constant demand for accident risks, which is called **driving intensity**. Safety measures lower the price for risky driving since (a) the potential accident becomes less probable and (b) the potential consequences of an accident are less severe. PELTZMAN concluded that such decreasing prices will lead to an increase in driving intensity.² Raising private demand for safety as well as new safety regulation produces lower accident costs. In contrast to an increasing demand for safety the new safety regulation induces a higher driving intensity. Even if the occupant's accident risk will be lowered by a safety measure the potential effects are not obtained. Increasing risks to pedestrians are expected. PELTZMAN questioned positive aggregated effects for all road user groups since a small decrease in accident risks of car occupants is exceeded by a disproportional increase in the accident risks of other road users.

Offsetting effects as investigated by PELTZMAN are also analyzed in risk homeostasis theory. PELTZMAN's concept and risk homeostasis differ in the considered groups as well as in the considered domain since PELTZMAN explicitly referred

² PELTZMAN assumed that driving intensity is a normal good. This term is quite unclear, since he did not specify a complete economic model. If we interpret normality as normality with respect to the price we usually have to consider a substitution effect as well as an income effect (see, e. g., VARIAN, 1999, p. 154).

to road traffic only.

2.2 The Concept of Risk Homeostasis

2.2.1 Risk Measures

Risk measures have to be defined in order to evaluate an individual's accident risk. They can refer to various aspects: subjective versus objective risks (COLBOURN, 1978), accident frequency versus accident severity risks (CHIRINKO and HARPER, 1993; BLUM and GAUDRY, 1999), and car-occupant versus non-occupant risks (PELTZMAN, 1975). Risk homeostasis theory is based on the accident frequency risk as well as the accident severity risk. The former refers to the risk of having an accident, while the latter covers the consequences of an accident. In the theory both risks are multiplied to get an overall risk measure (WILDE, 1982a).

In the control loop of the risk homeostasis theory two further risk measures are considered. Independent from any driving task, an individual risk level exists which the road user is willing to accept. This **target risk** is constant over a longer period of time. It acts as the reference point in the risk homeostasis theory and it is influenced by four factors (WILDE, 1982a; 1988):

1. the benefits of risky behavior,
2. the costs of cautious behavior,
3. the benefits of cautious behavior,
4. the costs of risky behavior.

Drivers evaluate advantages and disadvantages of risky behavior as well as of cautious behavior. For example, a more cautious behavior is associated with a higher probability of preventing an accident. The time costs of driving may increase since such a behavior may induce lower speeds. This evaluation leads to

the individual choice of the target risk level. Individuals are willing to accept this risk level to obtain their optimum with respect to the four factors. The target risk level varies among individuals since it depends on the individual results of the performed evaluations.

Risk homeostasis theory further includes an individual's **perceived risk**. It depends on the present (environmental) situation perceived by the road user. Typical environmental parameters influencing perceived risk are heavy traffic and road or weather conditions. In addition, the perceived environmental situation is affected by safety measures, e. g., airbag and ABS. Hence, the perceived risk is the result of the subjective evaluation of the actual environmental situation.³

The target risk as well as the perceived risk refer to a certain accident risk. The former is the individually accepted accident risk, while the latter is the accident risk in a certain situation or in a certain environment.

As mentioned above, COLBOURN (1978) distinguished between **subjective** and **objective** risks in driving tasks where the former was interpreted as the individual estimator of the latter.⁴ He turned to the term "perceived risk" since the driving environment changed rapidly. This concept is equal to the perceived risk in the risk homeostasis theory. Subjective risk and perceived risk were also equalized by HAIGHT (1986).⁵ Below we equalize both concepts. When we speak about the subjective risk we have in mind the perceived risk in terms of risk homeostasis.

³ Even if it is not necessary in risk homeostasis theory to figure out the perceived risk explicitly, an empirical investigation implemented by MANNERING and GRODSKY (1995) found that this risk measure is fairly close to the objective figure. This result may give further support to the applicability of the concept of perceived risk. MANNERING and GRODSKY found that motorcyclists are aware about the risks they take. The authors asked for the individual probability judgment of having an accident within the next ten years and computed the corresponding average yearly accident rate. Both figures were fairly close together. A further investigation to this topic was performed by NOLAND (1995) who also considered modal choice.

⁴ A similar pattern was given by MCKENNA (1988).

⁵ SUMMALA (1988) explicitly distinguished between both terms. The term perceived risk was, however, used in a similar manner as in risk homeostasis theory. Subjective risk was "reserved for 'arm-chair estimates' ... for research purposes" (p. 494).

2.2.2 The Homeostatic Control Loop

Even if the risk homeostasis theory is not only limited to road traffic (see WILDE, 1986a: 1988) its concept is usually described within this narrow domain regarding car drivers (WILDE, 1982a). The above-mentioned risk measures, target risk and perceived risk, determine an individual's behavior. The relative influence of the measures depends on the control loop. This control loop is homeostatic, which means that the behavior is chosen such that the perceived risk equals the target risk. A single driver chooses his individual driving behavior given (a) his own vehicle path, speed and direction, (b) the present road environment, and (c) the pathways of other road users (WILDE, 1982a, p. 210). The control loop as shown in figure 2.1 is an aggregation of drivers and other road users. It refers to a longer time frame (WILDE, 1982a, p. 211). Behavior will be adapted within a certain period of time (lagged feedback) as soon as differences occur between target and perceived risk. The length of this time period varies between a few seconds (suddenly occurring icy roads) and a few years (changing from left-hand traffic to right-hand traffic in Sweden, NÄÄTÄNEN and SUMMALA, 1976, cited by WILDE, 1982a).⁶

Road users compare their target risk with the perceived risk. The former is fixed, while the latter is determined by the drivers' perceptual skills (WILDE, 1982a, p. 212). The comparison leads to a decision about the adaptation of their individual driving behavior depending on the discrepancies between target and perceived risk. The easier a driving task appears to the driver the lower is the arousal of the driver. Drivers adapt their behavior given the perceived complexity of the current driving task (MAHALEL and SZTERNFELD, 1986). The adapting behavior is further determined by the individual's decision-making skills and the individual's vehicle handling skills. The former "refer to driver's ability to decide

⁶ EVANS (1985) introduced the term *behavioral feedback* since risk is not the only stimulus to induce behavioral changes. The effects after the introduction of a new safety measure and after other environmental changes are given by $\Delta S_{act} = (1 + f)\Delta S_{eng}$. ΔS_{act} is the observed effect and ΔS_{eng} is the expected effect by engineers. f is the parameter describing the behavioral feedback: it is equal to -1 in risk homeostasis.

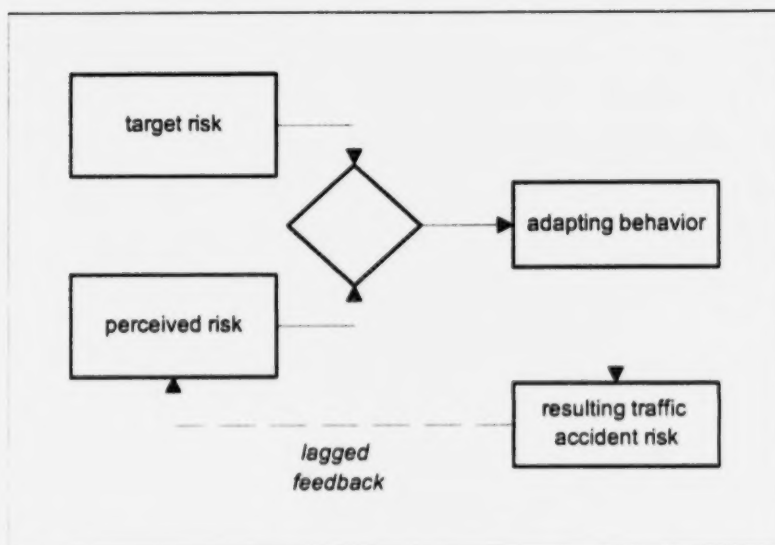


Figure 2.1: The control loop of the risk homeostasis theory, source: WILDE (1982a, p. 212)

what should be done in order to produce the desired adjustment", while the latter "determine whether the driver can effectively carry out what should be done for this purpose" (WILDE, 1982a, p. 212).

The three types of driver's skills mentioned might be improved by education or a corresponding ergonomic environment including road and car design. But they only affect the non-external parts of the control loop. Following WILDE, the unique external variable is the target risk and, therefore, the loop is exclusively controlled by this value. The target risk is the result of the evaluation of advantages and disadvantages of risky as well as of cautious behavior (see preceding section). Target risk only changes if the driver's attitude to risk changes.

2.2.3 Conclusions Concerning Road Traffic Safety

Since only changes in an individual's attitude to risk leads to changes in the resulting accident risk WILDE (1982a) concluded that only "motivational accident countermeasures aim at *reducing the target level of risk*" (WILDE, 1982a,

p. 220, WILDE's italics). Non-motivational safety measures, like the installation of airbags or mandated seat belt usage, do not affect a driver's attitude to risk; they only lower the perceived risk, since the driver becomes aware of the safety benefits after a while (lagged feedback). This induces him to adapt his behavior such that after adaptation the perceived risk equals the fixed target risk.

WILDE (1982a) referred to the risk measures *accident rate per vehicle kilometer*, *accidents per time unit of exposure*, and *accident rate per capita*, which behave in a different manner after the introduction of a new safety measure. WILDE concluded that non-motivational safety measures may yield economic benefits, like an increase in mobility (vehicle kilometers), since car driving becomes more attractive. This is, however, associated with higher driving risks at the per capita basis (WILDE, 1982a, p. 219).

Improvements in traffic safety can only be obtained if the driver's target risk decreases. First, the costs of risky driving or the benefits of cautious behavior may increase. Second, the benefits of risky driving or the costs of cautious behavior may decrease (see also chapter 2.2.1).

2.3 Supporting Evidence

2.3.1 Empirical Investigations

PELTZMAN (1975) investigated the effects of new standards for the safety design of new cars which were mandated in the U.S. in the 1960s (see chapter 2.1). He found almost no safety effects regarding the total death rate of all road users. He concluded that the considered regulation missed its target. The safety effects differed between car occupants and non-occupants. Occupants' safety increased at the expense of a decrease in non-occupants' safety. CONYBEARE (1980) found supporting data for risk homeostasis in the Australian seat belt wearing law. There the accident risk among car drivers decreases, but it increases in the pedes-

trian group, which is consistent with PELTZMAN's findings.⁷

CHIRINKO and HARPER (1993) presented a similar approach to risk homeostasis theory. They also suggested offsetting behavior, but they referred to other risk measures than those investigated by WILDE (1982a). They based their analysis on fatalities per 100 million vehicle miles. In their investigation CHIRINKO and HARPER considered (a) the regulation of car safety standards in the U.S. during the 1960s (see also PELTZMAN, 1975) as well as (b) the 55 mph speed limit introduced in the U.S. in 1974. The authors found insignificant effects of the safety measures on car occupants. The effects on non-occupants were significantly negative. The measure lead to an increase in non-occupants' fatality rate and, therefore, they concluded some offsetting behavior. They distinguished between two effects of a safety measure. First, the protection effect refers to the intention of the engineers when they develop new safety devices. Second, the substitution effect means that drivers enjoy the additional benefits of the safety measure by an adaptation of their behavior, e. g., by increasing their speeds.

In his 1982a study WILDE referred to numerous investigations confirming his theory. We already mentioned the study investigating the change-over from left-hand to right-hand traffic in Sweden (NÄÄTÄNEN and SUMMALA, 1976, cited by WILDE, 1982a). A complete offset of safety gains by their correct estimation was found by SCHREUDER (1969, cited by WILDE, 1982a). The usage rate of low-beam lights instead of parking lights in urban areas in the Netherlands increased from 37% to 80%. There not only did the accident rate persist, but also the ratio between nighttime and daytime accident frequency remained stable.

MAHALEL and SZTERNFELD (1986) found that technological improvements do not necessarily yield to a decrease in accident risks. The authors mentioned some examples for such improvements: new signals at intersections, installation of zebra crossings, and resurfacing of road sections. Drivers may perceive these improvements as a simplification of their driving task which decreases their arousal

⁷ Both studies, those by CONYBEARE (1980) as well as those by PELTZMAN (1975), are mentioned by WILDE (1982a) in favor of his risk homeostasis theory.

and, thus, the perceived risk decreases. If the simplification is overestimated then the arousal may not obtain the needed level to perform the driving task correctly. The probability of an accident, therefore, increases. MAHALEL and SZTERNFELD concluded that technological improvements may lead to a loss rather than a gain in traffic safety.

2.3.2 Theoretical Models

In a study by O'NEILL (1977) a model was presented where danger compensation in road traffic is discussed in an utility-theoretical context. O'NEILL modelled the degree of compensation given a rational driver.⁸ In order to maximize the benefits, which means to arrive as soon as possible given the expected losses of an accident, the driver can choose a corresponding speed. Since the driver may wrongly estimate the benefits of a safety measure, two results are possible: First, if the benefits are underestimated then the driver will choose a speed such that an increase in traffic safety is obtained. The chosen speed does not completely compensate safety benefits. Second, an overestimation of the safety benefits leads to a speed choice such that the resulting traffic safety, in fact, decreases. Safety benefits are compensated in this case.

UNDERWOOD ET AL. (1993) analyzed the costs and the benefits of risk taking (see figure 2.2). P specifies the risk drivers take and G refers to the corresponding gains. The authors concluded that a safety measure leads (a) to the same gains as before at a lower risk level (G'_1), (b) to higher gains at the same risk level as before (G''_1), or (c) to higher gains at a higher risk level (G'''_1). WILDE (1982a) and also UNDERWOOD ET AL. suggested that safety measures should be less conspicuous and should not be accompanied by publicity. Then individuals will not realize the possible benefits offered by the measure. They will not change their behavior, which means that risks will not increase to G'''_1 . This reasoning is,

⁸ A rational driver is defined as "one who has stable goals and optimally adjusts his behavior to maximize his expected gain in the face of a change in the driving environment" (O'NEILL, 1977, p. 158).

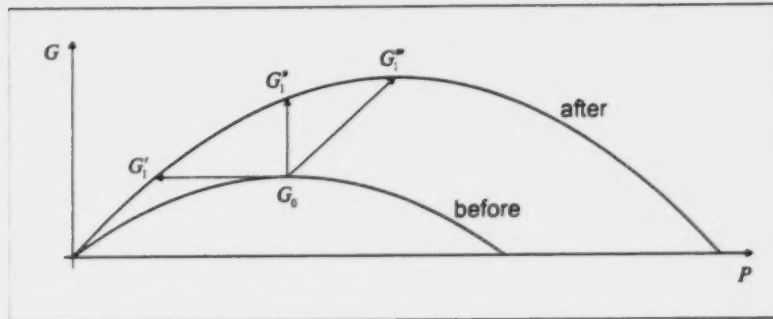


Figure 2.2: Gains before and after a new safety measure, source: UNDERWOOD ET AL. (1993, p. 283)

however, primarily focused to engineering safety measures (UNDERWOOD ET AL., 1993, pp. 281).

2.4 Counter-Evidence

2.4.1 Empirical Findings

CRANDALL and GRAHAM (1984) computed offsetting behavior by subtracting the actual from the expected safety effects by engineers. They found that the actual effects are even stronger than predicted in the car occupants' group. Offsetting behavior among various road user groups is confirmed. The decrease in pedestrians' safety is never completely compensated by the increase in car occupants' safety. Also SHANNON and SZATMARI (1994) could not confirm a decrease in safety in the non-occupants' group due to more frequent seat belt usage by car occupants.

EVANS (1996) investigated the effectiveness of several safety measures in light of the risk homeostasis theory. Analyzing the introduction of a seat belt wearing law in Britain during the mid 1980's, he found that "the consistency between predicted and observed casualty changes essentially precludes the possibility of any large change in driver behavior associated with changing from not wearing

to wearing a belt" (p. 10). EVANS did not completely neglect any behavioral changes. These changes and their negative consequences for safety were, however, small compared to the general decrease in fatalities and severe injuries. Reconsidering the British data, DULISSE (1997) found a compensation effect of only 7% to 13%.

The occurrence of risk compensation after seat belt legislation was questioned by JONAH and LAWSON (1984). They found that the fatality risk due to this safety measure decreases about 50-60% in Canada. In order to raise the risk level back to what it was, accident frequency has to increase by about the same amount. Compensation can also take place by an increase in accident severity in all of those accidents where no seat belt is worn. Both increases were judged as unrealistic by JONAH and LAWSON.

SHANNON (1986) investigated British figures for conformity with the risk homeostasis theory. Even if he observed a steady increase in deaths per capita in Britain between 1949 and the mid 1960's, which decreases to the initial level until 1983, he did not find support for the risk homeostasis theory. First, the theory is originally based on the ability of individuals to adapt their behavior. In this context such long periods are implausible. Second, "this pattern of declining deaths per capita since the mid 1960s is only compatible with Wilde's statements about RHT if there has been a decline in the benefit-cost ratio of vehicle use - yet there has been a substantial increase in the per capita use of motor vehicles, suggesting an increase in the ratio" (SHANNON, 1986, p. 1009).

The effectiveness of helmet-use laws for motorcyclists was analyzed by GRAHAM and LEE (1986). They discussed the actual effectiveness of helmet wearing. They referred to a statistic which shows that in 1981 in one third of all fatal accidents of motorcyclists in the U.S. a helmet was worn. Other investigations found that two-thirds of all motorcycle fatalities can be attributed to head injuries: Helmet usage could prevent 75% of these fatalities (WATSON ET AL., 1981, cited by GRAHAM and LEE, 1986). In their empirical evaluation GRAHAM and LEE found substantial support for the effectiveness of a strong helmet wearing law.⁹ The

fatality rate decreased about 12% to 22% which was slightly below the medical predictions. They concluded that these results cannot serve to support the risk homeostasis thesis. With respect to the weaker hypothesis of risk compensation as suggested by PELTZMAN (1975) they found no clear answer. If the actual medical predictions are at the lower end of the interval "then the results leave little room for immediate risk-compensation behavior" (GRAHAM and LEE, 1986, p. 266). After the repeal of strong helmet-use laws in most states in the U.S. during the late 1970s the death rates abruptly increased, but they only gradually decreased afterwards. Even if this finding indicates some behavioral feedback, it needs "five to ten years to offset totally the original jump" (GRAHAM and LEE, 1986, p. 266).

2.4.2 Theoretical Criticism

Offsetting Behavior

SLOVIC and FISCHHOFF (1982) referred to various situations where risk compensation does not work in the manner as predicted by WILDE (1982a). The current risk level might be unacceptably high, so that individuals may adopt safety measures rather than take compensatory actions. Such actions are, however, barely conceivable in various circumstances, e. g., after the installation of padded dashboards or after the installation of highway barriers (see also ORR, 1982). People may fail to correctly estimate the benefits of a safety measure. "If people already believe their personal risk to be extremely small, they may fail to recognize the risk reduction provided by a new safety device, hence, they may not act in ways that counteract their new safety gains" (SLOVIC and FISCHHOFF, 1982, p. 228).¹⁰ The appropriateness of the assumption that people are always able to estimate

⁹ "A 'strong' law applies to all cyclists while a 'weak' law applies only to teenagers" (GRAHAM and LEE, 1986, p. 256). Similar results with respect to the cyclists' safety were presented by ROBERTSON (1976), who additionally investigated the effectiveness of daytime headlamp laws.

¹⁰ In the extreme case the safety measure may not be visible at all and, then, an estimation is completely impossible.

the effects of a safety measure was also questioned by MCKENNA (1985). SLOVIC and FISCHHOFF (1982) mentioned a further shortcoming of risk homeostasis theory. Since some control variables are not exactly specified by WILDE (1982a), like the spatial frame or the time frame of homeostatic effects, "the theory does not appear to be falsifiable" (SLOVIC and FISCHHOFF, 1982, p. 230).¹¹

Applied Risk Measures

EVANS (1986a) investigated numerous U.S. figures and their support for risk homeostasis theory. This was done because of the wide variety of definitions of risk measures used in order to test the homeostatic behavior. EVANS analyzed deaths per vehicle miles travelled, which decreased quite substantially from 11.44 per 10^8 vehicle miles in 1943 to 4.43 per 10^8 vehicle miles in 1972. In order to get a constant risk level in terms of time of exposure the average speed would have to go up by about 158% in the same period.¹²

EVANS further referred to another risk measure, deaths per capita, which appears to remain at the same level between 1943 and 1972. There the car stock increased by about a factor of four and the population increased by about a factor of 1.5 in this period such that the vehicle stock per capita more than doubled. EVANS stated that "either the average vehicle in 1943 was driven for about 2.5 hr for every hour the average vehicle in 1972 was driven, or else the risk homeostasis theory is false" (p. 83).

¹¹ This was also stated by HUGUENIN (1988), but WILDE (1982b) rebutted this objection. He argued that risk homeostatic behavior is observable "in a particular geographical area over a specified time period" (WILDE, 1982b, p. 249).

¹² This was rebutted by WILDE (1986a, see also his 1988 paper) with the reason that average driving speed consists of car speed, bicyclists speed, walking speed, train speed etc.

Aggregation and Time Lag

The problem of aggregation in the risk homeostasis theory was investigated by COLE and WITHEY (1982). They questioned the shift from the micro to the macro level by WILDE (1982a). On the one hand, the individuals' viewpoint is investigated in the homeostatic control loop. On the other hand, the analysis moves to the aggregated viewpoint of the society by considering aggregated time series. This shift ignores the situation-specific character of the individual model. The authors distinguished three parameters which were aggregated in the model: time, driver, and traffic situation. At least the latter causes some problems during aggregation, since traffic situation "is a passive, fixed backdrop" in the individual model (COLE and WITHEY, 1982, p. 245).¹³

Like COLE and WITHEY (1982), MCKENNA (1985; 1988) also criticized the aggregation of individuals in the risk homeostasis theory. MCKENNA questioned the length of the time lag needed to adjust behavior so as to reach the prior risk levels. Since this differs under various circumstances it appears that risk homeostasis theory becomes untestable. Also EVANS (1985) disputed long-term behavioral feedback and its measurability because of the numerous other uncertainties affecting traffic safety and driving behavior. If long-term effects occur then risk homeostasis would "be universally correct in the long term", but "such a theory is not readily susceptible to experimental disproof" (p. 573).

Risk Homeostasis Thesis and Utility Theory

GRAHAM (1982) questioned whether there really are differences between the risk homeostasis theory and the expected utility theory.¹⁴ He mentioned some safety measures, like helmet use laws and the installation of seat belts in cars, leading to

¹³ This is widened by a fourth dimension the aggregation of adjustment actions (WILDE, 1982b).

¹⁴ In his response WILDE (1982b) pronounced the very narrow limits of expected utility theory in the context of traffic safety. This was also mentioned by SUMMALA (1988).

positive safety effects contrary to the predictions based on the risk homeostasis theory. A change in behavior is unlikely if accident severity is affected, which was confirmed by SAGBERG ET AL. (1997).¹⁵

Risk homeostasis was analyzed by JANSSEN and TENKINK (1988a;b) under economic aspects. They suggested a utility function where the accepted risk is selected by the choice of speed of the driver.¹⁶ They found some behavioral changes counteracting the expected benefits of a previously introduced safety measure. These adaptations had to be attributed to the motive of utility maximization of the driver and not to risk control. In light of this finding risk homeostasis is a by-product of the utility maximization. A homeostatic reaction is too strong of a requirement.¹⁷ JANSSEN and TENKINK suggested that "rather, some *degree* of negative feedback (compensation) must be considered to be the rule" (JANSSEN and TENKINK, 1988b, p. 431, JANSSEN and TENKINK's italics and parentheses). This is nothing else than what is usually called risk compensation (see e. g., PELTZMAN, 1975). Risk homeostasis is, insofar, a special case of risk compensation.

2.5 Summary

Table 2.1 summarizes the three general results of complete, partial, and no risk homeostasis as well as some representatives in literature. The distinction is not obvious since most of these investigations differ in the underlying risk measures

¹⁵ GRAHAM (1982) did not completely neglect offsetting behavior. He suggested that it is more likely to occur in those cases where accident frequency changed (see also LUND and O'NEILL, 1986). SAGBERG ET AL. (1997) found that taxi drivers adapt their behavior significantly as soon as an ABS is installed. They lower the time headway. Such behavioral changes cannot be observed if the car is equipped with an airbag. With respect to the certain situation (taxi driver's journey to the airport) they conclude that "this finding does probably not reflect behavioral adaptation to the car equipment" (p. 301).

¹⁶ Speed choice is based on a time-utility function rather than a speed-utility function as suggested by SUMMALA (1988, p. 493).

¹⁷ Also HUGUENIN (1988) questioned whether the complete offset is a reasonable requirement.

as well as in the investigated road user groups. We, therefore, summarize all analyses supporting one of the mentioned hypotheses in any context. Some of the above-mentioned investigations are not stated in the table, since sometimes a final conclusion is not drawn explicitly.

Table 2.1: Hypotheses of the degree of offsetting behavior and their representatives in literature

hypothesis	representative in literature
homeostasis	PELTZMAN (1975); CONYBEARE (1980); WILDE (1982a); CHIRINKO and HARPER (1993)
partial offset	GRAHAM (1982); CRANDALL and GRAHAM (1984); GRAHAM and LEE (1986); HUGUENIN (1988); JANSSEN and TENKINK (1988a;b); NOLAND (1995); EVANS (1996); SAGBERG ET AL. (1997)
no changes	SLOVIC and FISCHHOFF (1982); SHANNON (1986)

In table 2.2 the main objections of the risk homeostasis theory and their representatives in literature are summarized. The criticism is manifold. It ranges from fundamental objections concerning the falsifiability of the theory to detailed criticism, like the applied risk measures.

The variety of applied risk measures appears to be the most serious problem leading to the mentioned discrepancies. Depending on the selection of these risk measures, contradicting results may occur. This was already mentioned by WILDE (1982a), who stated that "the accident rate per vehicle kilometer may go down: per hour of exposure it will essentially remain the same and on the per capita basis it may go up" (p. 219). It is not even clear in numerous studies which of the three categories is applied, e. g., when the absolute annual fatality rates are investigated (see, e. g., PELTZMAN, 1975; CONYBEARE, 1980; GRAHAM and LEE, 1986).

Besides the mentioned problem concerning the applied risk measures, the risk homeostasis theory suffers from the fact that the considered domain is not explicitly limited. WILDE (1982a) originally considers the domain of road traffic which is also referred to in the above discussion. In his refutation of EVANS'

Table 2.2: Main objections of the risk homeostasis theory and their representatives in literature

	problem	representatives in literature
aggregation	aggregation across individuals	COLE and WITHEY (1982); MCKENNA (1985; 1988)
	spatial frame of homeostatic behavior	SLOVIC and FISCHHOFF (1982)
	time lag until complete offset	EVANS (1985); MCKENNA (1985; 1988); SHANNON (1986); GRAHAM and LEE (1986)
risk measures	applied risk measures	SLOVIC ET AL. (1978); MCKENNA (1982); EVANS (1985; 1986a)
	negative effects with respect to other road users	CRANDALL and GRAHAM (1984); SHANNON and SZATMARI (1994)
	measures affecting accident severity	GRAHAM (1982); LUND and O'NEILL (1986); SAGBERG ET AL. (1997)
empirical falsification	perceiveability of safety measures	SLOVIC and FISCHHOFF (1982); ORR (1982)
	existence of target risk	SLOVIC and FISCHHOFF (1982); MCKENNA (1988)
	falsifiability of the theory	SLOVIC and FISCHHOFF (1982); MCKENNA (1985; 1988); HUGUENIN (1988)

(1986a) criticism WILDE (1986a) widened this concept to travel in general. He argued that the average speed consists of car speed, bicycle speed, walking speed, train speed etc. We have to consider persons and their various travelling modes instead of vehicles (WILDE, 1986a, p. 97). Finally, WILDE (1986b) expanded the concept of risk homeostasis to completely different domains. He stated "that people, when they through whatever non-motivational measures or circumstances are made to take less risk to safety and health in the area to which these measures or circumstances apply, react by taking more risk in areas in which they do not"

(p. 392). If the risk homeostasis theory refers to one of the last two termed areas then all of the objections based on the domain of road traffic miss their target.

Before we implement a further empirical analysis we will discuss the considered domain as well as the underlying risk measures. The former will be done in the subsequent chapter, while the latter is associated with the considered empirical problem which is discussed in chapters 6 and 7.

Chapter 3

Risk Homeostasis Theory in Road Traffic: A Restatement

As discussed in the preceding chapter risk homeostasis suffers from the lack of a specified domain. The approaches of (a) various travelling modes (WILDE, 1986a) and (b) various risky domains (WILDE, 1986b) are quite useful, since they can explain a lot of diverse situations regarding risks and risky behavior. But this breadth leads to the danger that too many situations can be explained by different moderating parameters, which is the focus of some criticism (ADAMS, 1988; HUGUENIN, 1988).

As already mentioned in chapter 2.5, any investigation of risk homeostasis in a limited domain, like road traffic, is doomed, because the risk homeostasis theory is applicable in various domains. Two reasons, however, seem to support such a limited approach concerning the single domain of road traffic. First, this domain is an important field for safety discussions as the literature review in the preceding chapter showed (see also chapter 1). Second, the inclusion of further domains may lead to problems with the relevant parameters which should be investigated. Furthermore, an extensive definition of risk homeostasis appears to be inappropriate for empirical investigations since a useful database is hardly obtainable. Not even WILDE specifies satisfying empirical results. Nevertheless, the road traffic offers some interesting starting points in analyzing homeostatic behavior:

these will be discussed below in light of the already existing contributions to this topic. We will further derive a reformulated model of risk homeostasis, which only refers to this single domain. This serves as the fundament for the empirical investigation in chapters 6 and 7.

3.1 The Limited Domain of Road Traffic

The limitation of the risk homeostasis theory to the domain of road traffic offers two advantages. First, we have not to consider other travelling modes. Second, other domains than road traffic as propagated by WILDE (1986a;b) do no longer exist. Risk now refers to accident risks in road traffic only. This aspect is much closer to the intention of the road traffic planner when he evaluates accident risks in his domain. It also corresponds with the intention of many of the investigations mentioned in the preceding chapter.

3.1.1 The Effects of Exogenous Events

Most of the investigated safety measures in literature, like seat belt wearing (ROBERTSON, 1977; CONYBEARE, 1980; JONAH and LAWSON, 1984; SHANNON and SZATMARI, 1994), helmet-use law (GRAHAM and LEE, 1986), and improved car safety standards (PELTZMAN, 1975; CHIRINKO and HARPER, 1993), are interpretable as exogenous events to road traffic safety. They lead to some positive and negative safety effects in the short run and even in the long run. Such exogenous events are not only limited to safety measures. Other outstanding events, like German reunification in 1990, also affect traffic safety. They lead to an increase or a decrease in traffic safety, e. g., due to a change in traffic demand.

Road users, traffic planners, and the car producing industry (see chapter 1) might be interested in answers to the following questions:

1. Do exogenous events yield significant changes in accident risks in road traffic?

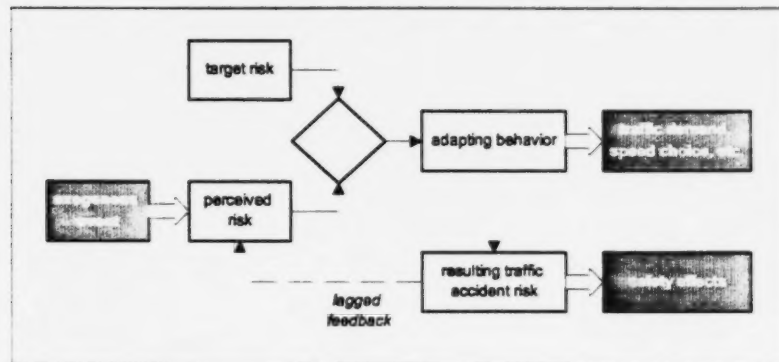


Figure 3.1: Effects of an exogenous event in terms of the risk homeostasis theory, source: according to WILDE (1982a, p. 212)

2. Assuming the first point is confirmed, do we observe offsetting behavior which counteracts the effects of the event regarding accident risks in road traffic?

Figure 3.1 visualizes the effects of an exogenous event with respect to the control loop in risk homeostasis theory. The target risk remains unaffected when we consider non-motivational safety measures, like seat belt wearing laws, or other events, like German reunification, since the attitude to risk does not change.

3.1.2 Exogenous Events and the Homeostatic Control Loop

WILDE (1982a) referred to two components affecting accident risk in road traffic. These are the accident frequency risk and the accident-severity risk (see also chapter 2.2.1). Both are multiplied to get the overall accident risk. With respect to risk homeostasis this differentiation appears to be a suitable starting point in order to investigate homeostatic effects, since exogenous events primarily affect only one of the two components. For example, after the installation of an airbag in a car a decrease in the severity of an accident is expected (see also chapter 4.1.2). As soon as individuals become aware of the benefits of an airbag they relocate their risk taking by changing their driving behavior, e. g., by an

increase of their driving speed. The accident frequency increases and, therefore, the lowered accident severity is accompanied by a higher accident frequency. This can be termed as **risk substitution**. If a complete substitution occurs due to an exogenous event, which means that the decrease in accident severity is completely compensated by the corresponding increase in accident frequency, the overall accident risk in the homeostatic control loop is balanced. On the one hand, we observe positive safety effects in one of the two risk components. On the other hand, negative effects occur in the other component.

This explicit discrimination of the two risk components is not yet considered in literature. The investigations mostly refer to another form of risk substitution, namely the substitution between various road user groups, like car occupants and non-occupants (see, e. g., PELTZMAN, 1975; CONYBEARE, 1980; CHIRINKO and HARPER, 1993). This might be attributed to the difficulty in evaluating the extent of the offset. It is not even clear which increase in accident frequency risk is required to equate a certain decrease in accident severity risk and vice versa. Even if we cannot sufficiently solve the problem of the complete offset, we may find some empirical evidence supporting or refuting the risk substitution thesis.

Beside risk substitution another relevant aspect concerning homeostatic risk taking in road traffic is the long-run offset of the observed safety effects as the result of an exogenous event. Assuming that risk substitution does not occur, which means that only one of the two risk components in road traffic changes, we may observe an adjustment to the risk level prior to the event in question. Thus, the control loop is balanced after this adjustment process. This effect is termed **risk adjustment**. It is already analyzed in other investigations (see, e. g., EVANS, 1986a; SHANNON, 1986).¹ It is, however, not yet done with the German experience.

The most serious problem, which arises with risk adjustment, is the length of

¹ An example for such an adjustment process is mentioned by WILDE (1982a). He referred to the change from left-hand traffic to right-hand traffic in Sweden. There the process of risk adjustment needed about two years (NÄÄTÄNEN and SUMMALA, 1976, cited by WILDE, 1982a, see also chapter 2.2.2).

the time lag until the complete offset. Time lags of several decades are questioned by SHANNON (1986). The problem of the time lag is not easy to solve. We are, therefore, looking for empirical evidence supporting or refuting the risk adjustment hypotheses. The confirmation or the refutation of a complete offset is not our goal. We may find some indicators which point in one of the following directions. Either risk adjustment is favored, or risk adjustment is not favored.

Both effects, risk substitution and risk adjustment, may occur separately as well as simultaneously. Furthermore, we may not observe any risk substitution at all, but only risk adjustment in both of the risk categories. The accident frequency risk as well as the accident severity risk changes. Both changes are followed by two corresponding adjustment processes. We should also note that we will only consider **additional effects** due to the event under consideration. Already existing time trends in the risk measures are not discussed. We focus on **deviations** from the already existing time trends in the risk measures after the event in question was taken place. In this context risk adjustment means that the risk measure returns to the overall time trend prior to the considered event. Risk substitution after an exogenous event means that the accident frequency risk exceeds its former time trend while the accident severity risk falls below its former time trend, or vice versa. Below we will sometimes speak about increasing or decreasing effects due to the event under consideration which refers to the already existing time trend. For example, increasing effects are also stated if the time trend before the event in question as well as after this event is negative. But the time trend after the event might be less steep such that the time series deviates more and more from the expected time trend if the event had not taken place.

3.2 Summary

Since our analysis is limited to a specific domain, only a few of the problems stated in table 2.2 are subject to discussion. These are summarized in table 3.1. The problem of aggregating individuals is not discussed since it differs between the risk of a single individual and the risk of a group of individuals after aggregation. We

will analyze aggregated macro data (see chapter 4.3) and, therefore, we assume that changes at the individual level also affect aggregated risk measures. This is frequently done in many other investigations analyzing accident risks in road traffic (see, e. g., CONYBEARE, 1980; EVANS, 1986a; 1996; GRAHAM and LEE, 1986; SHANNON, 1986). The spatial frame of the investigation is limited to West Germany until German reunification and to all of Germany after this event. Since we do not consider a complete offset, the time lag is of less interest. When we analyze long-term adjustments we will only be interested in the general tendency of these adjustments. The applied risk measures refer to accident severity as well as to accident frequency, since we are looking for risk substitution. Risk substitution among different road user groups is not a subject of the discussion. We analyze risk measures covering all road user groups (see chapter 4.3). Because of the aggregated data pool, the amount of the target risk is not investigated.

Table 3.1: Considered problems in the risk homeostasis theory and their relevance in the study

	problem	relevance
aggregation	aggregation across individuals	not discussed
	spatial frame of homeostatic behavior	Germany/(West) Germany
	time lag until complete offset	not discussed, general tendency only
risk measures	applied risk measures	accident frequency and accident severity
	negative effects with respect to other road users	not discussed (all road users included)
	measures affecting accident severity	discussed
empirical falsification	perceiveability of safety measures	not discussed
	existence of target risk	not discussed
	falsifiability of the theory	irrelevant (limited domain)

It is, furthermore, not discussed whether the events in question are explicitly perceived by the individuals. The choice of a very narrow domain limits the possibility to falsify the theory.

Chapter 4

Exogenous Events and their Relevance to Traffic Safety

In this chapter we introduce the outline of the empirical analysis which is realized in the subsequent chapters. The intention of the analysis is the investigation of the risk homeostasis thesis of the adjusted model (see chapter 3) in respect to two different events, (a) the intensified seat belt legislation in Germany in August, 1984 and (b) German reunification in 1990. Both events refer to the limited domain of road traffic.

The outline of this chapter is as follows. First, we consider the relevance of the two contexts in light of the risk homeostasis theory. Then we describe the applied database.

4.1 The Intensified Seat Belt Legislation

Below we will analyze the effects of the introduction in August, 1984, of a **penalty for not using the seat belt** while driving a car. Prior to this date the use of the belt was regulated but disuse was not punished in Germany.¹ Since August, 1984,

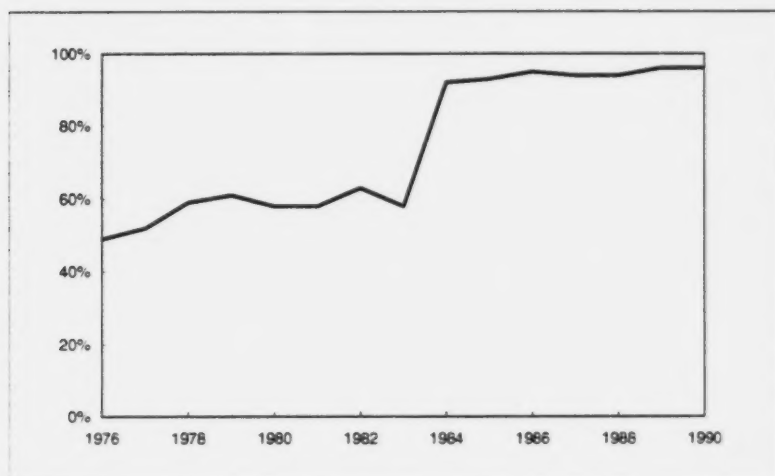


Figure 4.1: Average seat belt usage rate in West Germany, sources: DIW (1988, p. 135) and DIW (1993, p. 150)

car passengers have to pay DM 40 if they do not use the belt. Meanwhile this penalty increased to DM 60. After the introduction of the penalty the average belt-usage rate of front seat passengers increased suddenly from less than 60% to approximately 95% as shown in figure 4.1.²

4.1.1 Seat Belt Legislation and Usage Rates in Other Countries

A similar increase in the seat belt usage rate as shown in figure 4.1 was found by HAKKERT ET AL. (1981) in Israel. In this country the legislation came in July, 1975. A penalty was introduced for not using seat belts on interurban roads only: disuse was not punished in urban areas. The usage rate rose from less than 10% to more than 70% on interurban roads. But almost no effect could be found

¹ In Germany seat belt legislation was introduced in January 1976.

² The stated figures are observed in fall (mostly in September) in the corresponding year. Similar patterns can also be found in Illinois, USA (ROCK, 1993), but not to the same extent, and in the U.K. (EVANS, 1991).

on urban roads. Although the usage rate rose to more than 30% in July, 1975, it dropped back to less than 10% in the next field study in July, 1976. As in Germany, the rise in the usage rate could primarily be attributed to the penalty.³ The exception of urban roads in Israel may cause drivers to disuse the seat belt while driving in urban areas. This is not observable in Germany where such an exception does not exist.⁴ JONAH and LAWSON (1984) reported increasing usage rates in Canada from 20% to 70% during peak, dropping to the 50% level in the long run. They observed these rates in several Canadian provinces between 1975 and 1982, where seat belt laws came into effect at various dates during this period. Similar figures can be found in North Carolina, USA: The usage rate increased from 25% to 45% without any existing penalty (HUNTER ET AL., 1993a).⁵ It reached a peak of 78% right after the introduction of a penalty. But the rate decreased to 60% one year later. These figures are quite different from the German experience where no decrease in the usage rate of seat belts is observable after the introduction of a penalty even in the long run.⁶

Given the increased usage rate after the implementation of fines, we can expect

³ This abductive reasoning was questioned by NELSON and MOFFIT (1988). They reviewed several theoretical models which have been successfully used in health education programs. They pronounce voluntary changes in individual behavior beside seat belt legislation and enforcement. As frequently shown, these measures are not as successful as compulsory measures. But enforcement is also not unlimited in its success. TURBELL ET AL. (1997) analyzed the failure of compulsory interlock systems in the U.S. during the mid 1970s. Such systems prevented the start of the car as long as all front seat passengers were unbelted. First, these systems were not very sophisticated. For instance, they also prevented sitting in the car with the engine idling. Second, and this seems to be most important, such systems were not yet in common use, since people felt that it was an infringement of personal freedom.

⁴ BERGAN ET AL. (1977) found a similar pattern in Saskatchewan, Canada, as in Germany. In absence of enforcement the usage rate rose from 18% to 53%, while seat belt legislation led to a rate of 77%.

⁵ This was confirmed by WAGENAAR ET AL. (1988) for numerous states in the U.S. Usage rate peaked typically within a few months after the implementation of the legislation.

⁶ Analyzing figures in North Carolina, USA, HUNTER ET AL. (1993a) investigated a special program raising the belt usage rate by public information, education, and inexpensive economic incentives. This program, in fact, reached its goal, but usage rate did not obtain German extents despite the program and the penalty. In the optimistic case the usage rate rose from 48% before the program to 68% at peak during the program. The general effectiveness of such programs was questioned by RIVARA ET AL. (1999).

some positive effects on safety. Changes in **accident severity** are especially likely to occur. The effectiveness of seat belts as a safety device was pronounced in several publications which we will discuss below.

4.1.2 The Safety Effects of the Seat Belt

The effects of seat belts in cars were pronounced in various publications. We will now shortly discuss the results and outline the relevance of further investigations in Germany.

The research of this topic began in the 1970s. First, safety effects of different belt systems in cars were investigated (see, e. g., GRIME, 1979). In the meanwhile any car in Germany was equipped with three-point safety belts which provided upper torso restraint. Sometimes the middle belt in the back seat is a two-point belt. We will not discuss the differences of these belt systems, but we will refer to the effects of seat belt usage in general. GRIME (1979) reviewed the main aspects of seat belt effectiveness. The most important function of seat belts is the **protection of the head and body** in frontal impacts, which constitute 60% of all traffic accidents (GRIME, 1979, p. 293). This was also confirmed by ARAJÄRVI (1988) in his investigation of Finnish data.⁷ A wide variety of investigations found decreasing fatality rates due to seat belt usage (HAKKERT ET AL., 1981 analyzing Israeli data, CAMERON, 1981 analyzing Australian data, WAGENAAR ET AL., 1988 analyzing U.S. data, ARAJÄRVI, 1988 analyzing Finnish data, COOPER, 1994 analyzing Canadian data, PETRIDOU ET AL., 1998 analyzing Greece data). Based on the fatality rate, the computed seat belt effectiveness ranged from 6% (HAKKERT ET AL., 1981) to 49% (COOPER, 1994) in preventing fatal consequences.⁸

Some investigations refer more generally to the decrease in the severity of an

⁷ ARAJÄRVI (1988) pointed out that there are statistically more fatalities in lateral impacts than frontal impacts.

⁸ Such optimistic results were questioned by DEE (1998). He estimated the increase in belt usage rates and attributed only a small decrease in fatalities to it.

accident. This particularly includes the already mentioned decreasing fatality rates as well as decreasing injury rates (JONAH and LAWSON, 1984 analyzing Canadian data, again ARAJÄRVI, 1988, SALMI ET AL., 1989 analyzing French data, LOEB, 1993; 1995 analyzing U.S. data, again COOPER, 1994). COOPER (1994) computed a seat belt effectiveness of 35% in preventing severe injuries which is somewhat below the figure regarding fatalities.

While all of the investigations of seat belt effectiveness come to the same result in severe accident consequences, this is no longer the case regarding less severe injuries. Already GRIME (1979) discussed the problem of the **increase of specific injuries** as a result of seat belt usage. This particularly refers to light injuries. For example, CAMERON (1981) pointed out that seat belt wearing leads to an "increased likelihood of minor injury to the thorax and lower torso among victims who were injured" (p. 24). One may object that this comes from the prevention of former severe injuries, but CAMERON argues that "minor injuries are not artefacts ... of the reduced likelihood of severe injury ... when the seat belt is worn, but are due to the wearing of the seat belt." (p. 24). In contrast, COOPER (1994) found a safety belt effectiveness of 11% in preventing minor-injury crashes. Since completely prevented injuries were no longer counted in CAMERON's study his finding is not inconsistent with the above-mentioned results. The results are, however, ambiguous. On the one hand, seat belt usage may cause some minor injuries, while on the other hand, minor injuries are completely prevented.

4.1.3 Further Findings Concerning Seat Belt Usage

As already described in chapter 4.1.1 increased belt usage due to changing seat belt legislation frequently drops after a while. This may attenuate the achieved safety effects in severe accident consequences (HAKKERT ET AL., 1981; JONAH and LAWSON, 1984; RIVARA ET AL., 1999). Empirical results considering this problem are ambiguous. LOEB (1993) found that in California, USA, the safety effects in the first quarter in single-vehicle accidents exceeds those in the subsequent quarter. But in contrast, the results in Texas, USA (LOEB, 1995), showed some evidence that the safety effects in the subsequent quarter were larger than

those in the first quarter, which might be attributed to the introduction of an additional penalty in Texas in the subsequent quarter.

Some studies dealt with the problem of demographic differences between seat belt users and non-users (HUNTER ET AL., 1993b; STEWART, 1993; LI ET AL., 1999). They found some differences depending on socio-demographic parameters, like age, gender, and reported annual mileage. Belt usage had significant effects on accidents and injury rates even after adjusting for those mediating factors. Some studies additionally found that non-users not only have higher injury rates, but also higher accident rates (REINFURT ET AL., 1990; TURBELL ET AL., 1997). Because of the expected effects of the seat belt (GRIME, 1979), the first finding is not very surprising but the second one is. We would not have expected changes in accident frequency. These results mean that in general **non-users of the seat belt take higher risks than users** (COOPER, 1994). A seat belt law and particularly its enforcement concerns hard-core non-users. The usage rate in this group rises and this lowers their higher accidents risk compared to voluntary belt users. The decrease in the average accident risk is also disproportionally high (TURBELL ET AL., 1997).⁹

RIVARA ET AL. (1999) investigated differences between **primary and secondary enforcement** of seat belt legislation.¹⁰ Some differences between the U.S. and other countries were found. Secondary enforcement was common practice in the U.S. in contrast to most other countries where primary enforcement was usual.¹¹ RIVARA ET AL. found that primary enforcement is "more likely to achieve the goals of legislation than are secondary enforcement laws" (p. 36). DEE (1998) found that the difference in belt usage rates regarding both enforce-

⁹ TURBELL ET AL. (1997) suggested the implementation of interlock systems to guarantee usage rates of 100%. Since these systems are quite expensive and the usage rates in Germany are already high, positive effects are questionable. Furthermore, the acceptance of such systems is problematic as already discussed (see footnote 3, p. 33).

¹⁰ Primary enforcement means that drivers are stopped by the police for no other offense than being unbelted. Secondary enforcement allows police intervention only if other reasons arise, e. g., speeding. Seat belt offense is then punished in addition to the other offense.

¹¹ 13 U.S. states introduced primary enforcement in the meantime (RIVARA ET AL., 1999, p. 31).

ment laws is substantial. He estimated increases in usage rates in the U.S. by about 46.4% with primary enforcement laws and by about 24.4% with secondary enforcement laws (DEE, 1998, p. 3).¹²

4.1.4 Concluding Remarks

In table 4.1 the most important empirical studies, which refer to the expected safety effects of seat belt usage, are summarized. It becomes obvious that the safety belt primarily prevents most severe accident consequences, like fatalities and severe injuries. It is not even clear what happens to less severe accident consequences, like minor injuries.

Table 4.1: Safety effects of the seat belt usage and some representatives in literature

effects	representatives
general decrease in accident severity	JONAH and LAWSON (1984); SALMI ET AL. (1989); LOEB (1993; 1995)
decrease in fatalities	HAKKERT ET AL. (1981); CAMERON (1981); WAGENAAR ET AL. (1988); EVANS (1986b); ARAJÄRVI (1988); COOPER (1994); PETRIDOU ET AL. (1998)
decrease in severe injuries	CAMERON (1981); COOPER (1994)
prevention of minor injuries	COOPER (1994)
increase in light injuries	CAMERON (1981)
decrease in safety effects in the long run	LOEB (1993)

The last safety effect listed in table 4.1, decreasing safety effects in the long run, refers to some problems of seat belt legislation as stated in table 4.2. Dropping

¹² The different effects in the fatality rate between the two types of enforcement in the U.S. were analyzed by WAGENAAR ET AL. (1988). They found that primary enforcement leads to a significant decrease in fatalities by about 9.9% while secondary enforcement leads only to a decrease at about 6.7%.

usage rates cannot be observed in the long run in Germany as shown in figure 4.1 and, therefore, this source of decreasing safety effects is not considered any longer. Furthermore, secondary enforcement as another source of non-optimal safety improvement after seat belt legislation can be neglected in Germany since only primary enforcement is common practice.

Table 4.2: Problems of the seat belt legislation and some representatives in literature

problem	representatives
decreasing usage rates in the long run	HAKKERT ET AL. (1981); JONAH and LAWSON (1984); RIVARA ET AL. (1999)
sociodemographic differences between belt users and non-users	REINFURT ET AL. (1990); HUNTER ET AL. (1993b); STEWART (1993); LI ET AL. (1999); TURBELL ET AL. (1997)
differences between primary and secondary enforcement	WAGENAAR ET AL. (1988); RIVARA ET AL. (1999); DEE (1998)

Because of the persistence of the increased seat belt usage in Germany as shown in figure 4.1, an empirical test of risk homeostasis in the limited domain of road traffic will be of particular interest. The above-mentioned facts allow us to expect substantial safety effects after the intensification of seat belt legislation in Germany in August, 1984. Based on the risk homeostasis theory by WILDE (1982a), we would, however, not predict that intensified seat belt legislation changes a driver's attitude to risk (see also chapter 3.1.2) and, thus, safety effects are questionable within this theoretical concept.

4.2 German Reunification

The collapse of the communist system in eastern Europe does not only affect Germany, but all of the other European countries as well. Between West and East Germany there exist substantial differences in fundamental indicators determining road safety, e. g., road infrastructure, and the modernity of the car fleet.

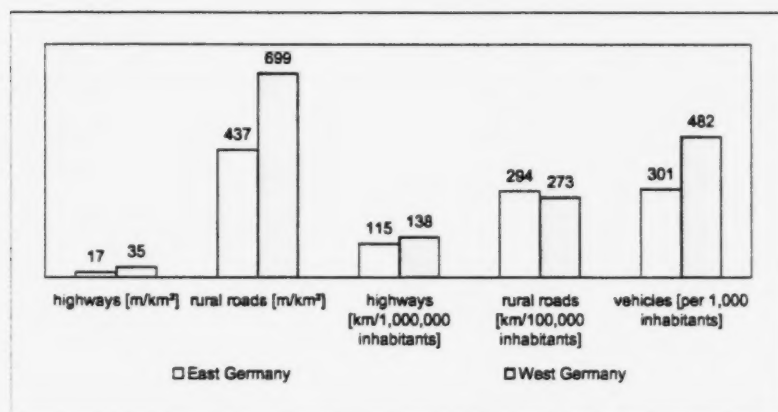


Figure 4.2: Road infrastructure and car fleet in East as well as in West Germany in 1990, sources: DIW (1993, pp. 99, 104, 132, 296, and 309) and IDW (2000, table 1)

Through German reunification the situation of traffic was externally changed. There are reasons to expect changes in traffic safety, too. Below we will give a short overview of these indicators and the actual differences between both parts of Germany.

4.2.1 Differences in the Infrastructure

Most evident are the substantial **differences in the infrastructure** between West and East Germany. These differences in the highway as well as rural road network are shown in figure 4.2. Roads in the East are less developed than in the West; this becomes especially obvious if we look at the highways. Even if we relate this figure to the population the East German figure is smaller than the West German one, although the density of the population in the East is much smaller than in the West.

The same occurs in the car fleet. It is not only smaller in the East (based on the population), but also much older compared to the West. First, car life-cycles in the East are much longer, since production never met demand.¹³ Second, cars

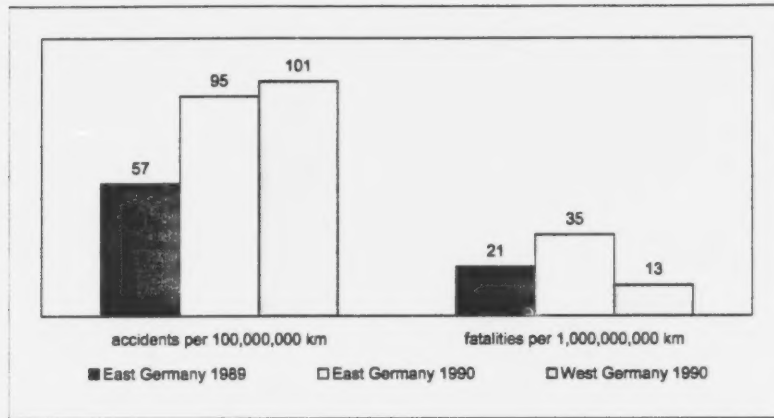


Figure 4.3: Accidents and fatalities in East as well as in West Germany, source: DIW (1993, pp. 99, 132, 146, 151, 296, and 309)

in the East are not the most state of the art in terms of comfort, security, and fuel efficiency. They do not achieve western safety standards, too. Cars are not equipped with safety devices, like ABS and airbag systems.

The shown figures may clarify the backlog in the East German infrastructure. Some projects solving these problems are stated in BMV (1992). They particularly consider the road network.

4.2.2 Differences in Road Traffic Safety

Comparing the two parts of Germany, differences become evident if we look at the road traffic fatality rate as well as the accident rate (see figure 4.3). In East Germany the accident rate in 1989 was much less than in 1990, where it almost doubled and nearly obtained the western level. Much more substantial than the accident variation are the differences in the fatality rate which is almost three times higher in the East than in the West in 1990.

¹³ One had to wait an average of more than 10 years to get a new car.

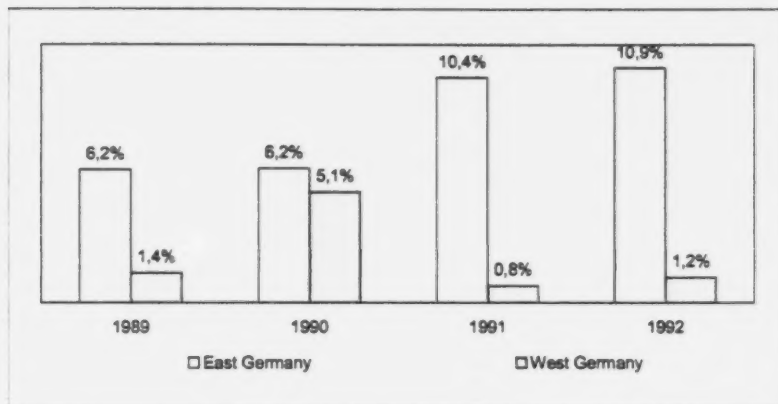


Figure 4.4: Changes in the traffic demand in East as well as in West Germany (person kilometers driven), source: DIW (1994, pp. 212 and 313)

ERNST ET AL. (1991) and BRÜHNING ET AL. (1993) investigated the differences in traffic safety between East and West Germany. They found substantial differences in fatalities on different road types. In 1990 only 11.8% of all fatalities in the West occurred on highways, but 17% in the East. In the case of highway accidents with bodily damages the discrepancy is still higher. In 1990 38 fatalities per 1,000 accidents occurred in the West, but 170 in the East.

In the East, but also in the West individual road traffic demand as well as demand for goods carried on roads increased (see figures 4.4 and 4.5). The 1990 decrease in goods carried in East Germany may come from the collapse of industrial production, especially in sectors with high transport volumes. The increase in individual traffic occurred earlier (in 1990) than the increase in the carried goods (starting in 1991).

4.2.3 Concluding Remarks

Figures 4.2-4.5 make it obvious that German reunification was a crucial event affecting road traffic safety. Like changing seat belt legislation, German reunification did not change a driver's attitude to risk (WILDE, 1982a). We may

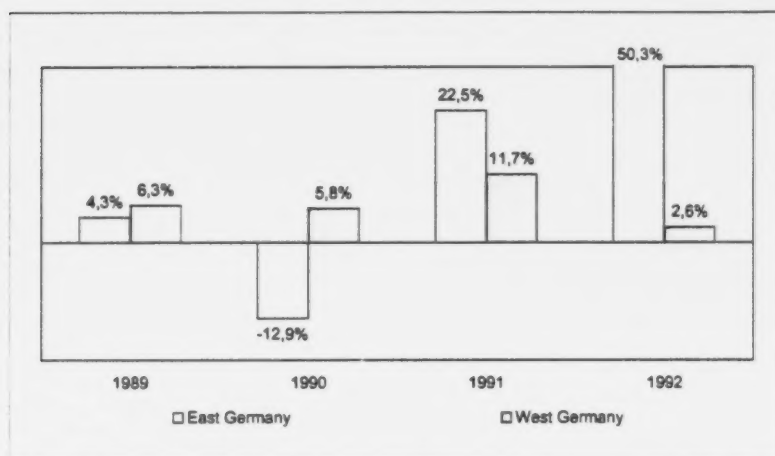


Figure 4.5: Changes in the traffic demand in East as well as in West Germany (tons of goods carried on roads), source: DIW (1994, pp. 228 and 314)

observe a balanced homeostatic control loop in the limited domain of road traffic (see figure 3.1) because of risk substitution and risk adjustment.

The road traffic planners are also interested in the long run trends. Their goal might be the attainment of similar road safety situations in East and West Germany. In order to achieve this objective they may use the expected road accident risk in West Germany in the 1990s, assuming that German reunification has not taken place.

4.3 Database and Risk Measures

As mentioned in chapters 2.2.1 and 3.1.2 accident risk is divided into accident frequency risk and accident severity risk. Both of these categories were frequently investigated, e. g., by WILDE (1982a), GRAHAM (1982), JONAH and LAWSON (1984), LUND and O'NEILL (1986); SAGBERG ET AL. (1997), BLUM and GAUDRY (1999), and KALUS (2000). In order to evaluate traffic accident risks within these two categories various risk measure have been established, which will be discussed

below.

In contrast to WILDE (1982a), who particularly referred to the risk measure of time of exposure, other studies investigated accident frequency risks on the basis of traffic demand in various circumstances as shown in table 4.3. All of these studies applied time series analysis as we will do below, while others were based on cross-sectional data (see, e. g., EVANS, 1986b; ARAJÄRVI, 1988; JANSSEN, 1994; RIVARA ET AL., 1999). The first category in the table refers to absolute figures as is usually stated in official statistics. In the other categories specific figures are computed which refer to a certain period of time.

Table 4.3: Risk measures of road accident risks and their representatives in literature

risk measure	representatives (samples)
absolute figures per year/month	GRIME (1979); LUND ET AL. (1987); SALMI ET AL. (1989); LOEB (1993; 1995); MOLLETT (2000)
accidents per kilometers driven	EVANS (1986a); BLUM and GAUDRY (1999); MOLLETT (2000)
accidents per fuel sales	WAGENAAR ET AL. (1988)
victims per kilometers driven	JONAH and LAWSON (1984)
victims per accident	CAMERON (1981); BLUM and GAUDRY (1999)

Seat belt legislation is principally focused on accident severity, namely the bodily damages that result. We refer to the number of accidents with bodily damages if we analyze accident severity risks. This procedure is similar to the studies by CAMERON (1981) and BLUM and GAUDRY (1999). Because of risk adjustment processes by the adaptation of drivers' behavior, also accident frequency may change after seat belt legislation. Therefore, also the accident frequency risk has to be considered below. Some light injuries may completely be prevented by the seat belt so that the accident is no longer counted as an accident with bodily damages, but with material damages. In order to cover this specific case we have further to consider accidents with material damages. With respect to

accident frequency, measures based on traffic demand would be most suitable, since they take the benefits of participation in road traffic into consideration. One option is the measure *accidents per kilometers driven* as already done by BLUM and GAUDRY (1999) and MOLLETT (2000). Very important for a meaningful empirical investigation are the availability and the reliability of the employed time series. Kilometers driven as the basis for accident frequency cannot easily be obtained since this distance is based on estimations on a yearly basis. Because of the applied econometric methodology we need monthly data and, thus, we use a second option, the accident figures per fuel sales as already investigated by WAGENAAR ET AL. (1988).

In order to investigate the two events in question we use the SNUS¹⁴ database which is also employed in some earlier studies, e. g., BLUM and GAUDRY (1999) and KALUS (2000). The analysis is based on monthly data from January, 1968, until December, 1998. Figures of traffic accidents, injuries, and fatalities are available for West Germany from January, 1968, until December, 1998, and for East Germany from January, 1991, until December, 1998. We can analyze

1. effects of changing seat belt legislation in West Germany,
2. effects of German reunification in West Germany given changes in seat belt legislation,
3. effects of German reunification, i. e., comparison of Germany's figures after reunification to West German figures before this event.

As already said we distinguish between accidents with **material damages** and accidents with **bodily damages**.¹⁵ Victims are divided into three groups, **lightly injured persons, severely injured persons, and fatalities**. Beside these

¹⁴ SNUS abbreviates *Straßenverkehrsnachfrage, Unfälle und deren Schwere* which can be translated as *Road Demand, Accidents and their Severity*.

¹⁵ Official statistics contain two categories of material damages, namely light and severe material damages. Since the categorization changed several times we aggregate both into one group.

Table 4.4: Description of the considered risk measures

risk measure	operational definition
fatalities	absolute number of fatalities per 1,000 accidents with bodily damages
severely injured	absolute number of severely injured per 1,000 accidents with bodily damages
lightly injured	absolute number of lightly injured per 1,000 accidents with bodily damages
accidents with bodily damages	absolute number of accidents with bodily damages per 1,000 accidents with bodily or with material damages
accident frequency	number of accidents with bodily damages as well as with material damages per 1,000 tons of fuel demand

various categories of accident severity we also consider the accident frequency. There we compute the ratio of the number of accidents and the traffic demand. The used indicator for the traffic demand is the figure of the fuel sales.¹⁶ In table 4.4 the considered risk measures are summarized.¹⁷ All of these measures are specified with respect to the West German focus. They contain monthly West German data from January, 1968, until December, 1998. We also consider reunified Germany, which means that the series contain West German data from January, 1968, until December, 1990, and German data from January, 1991, until December, 1998.

¹⁶ The 1990 figures of fuel sales are biased since fuel production in West Germany was partly sold to Eastern Germany. The portion of these sales is unknown. Because of this bias, our analysis on the effects of German reunification is limited to accident severity.

¹⁷ When we talk about fatalities, for example, we have in mind fatalities per 1,000 accidents with bodily damages, unless something else is explicitly noted.

4.4 Hypotheses

Below we derive hypotheses from the discussion in the preceeding chapters. They are the basis of the empirical analysis and will be reformulated in operational terms after having introduced the econometric methodology in the subsequent chapter.

4.4.1 The Intensified Seat Belt Legislation

Since belt wearing primarily affects fatalities and the most severe of injuries we can expect changes in these risk measures. It is very unlikely that one of the three measures, fatalities, severely injured persons, and lightly injured persons per accident persists if the other two change due to the event in question. If an accident is classified as an accident with bodily damages this implies that there exists at least one victim in one of the three groups. Because of this property of the applied risk measures we can also expect changes in minor injuries. The proportion of accidents with bodily damages may also change depending on the event under consideration. On the one hand, injuries are completely prevented. On the other hand, seat belt wearing may cause some minor injuries, which would be prevented if the belt is not worn (see, e. g., COOPER, 1994).

Beside these **suddenly occurring effects** we also presume some long-term effects on risk adjustment. If we observe sudden effects then in the long run the risk may adjust to the trend prior to the event. This is denoted as **changes in the long run**.

Hypothesis 1.1: *The intensified seat belt legislation leads to a short-run change as well as to a long-run change in fatalities per accident with bodily damages.*

Hypothesis 1.2: *The intensified seat belt legislation leads to a short-run change as well as to a long-run change in the number of severely injured*

persons per accident with bodily damages.

Hypothesis 1.3: *The intensified seat belt legislation leads to a short-run change as well as to a long-run change in the number of lightly injured persons per accident with bodily damages.*

Hypothesis 1.4: *The intensified seat belt legislation leads to a short-run change as well as to a long-run change in the ratio of accidents with bodily damages and all types of accidents.*

Seat belt wearing particularly affects accident severity. Since we are analyzing risk substitution effects, there may also occur changes in accident frequency.

Hypothesis 1.5: *The intensified seat belt legislation leads to a short-run change as well as to a long-run change in accident frequency.*

4.4.2 German Reunification

The analysis of German reunification is divided into two parts, West Germany on the one hand and reunified Germany on the other, since the situation may differ between West and East Germany. Since East German figures before the reunification are not available in the desired quality (see chapter 4.3) we cannot investigate East Germany by itself. We, therefore, analyze (a) West German figures before and after reunification and (b) figures containing East **and** West German data after reunification; and we compare them with the figures in West Germany prior to the event in question. The latter analysis describes the situation in reunified Germany in comparison to the expected situation in West Germany if this event had not taken place. In order to compute accident frequency, figures of fuel sales are needed. Since valid 1990 figures for fuel sales are not available for West Germany we limit our investigation to accident severity.

4.4.2.1 West Germany

The car fleet of East Germany at the beginning of the 1990s did not match the safety standards of the West. Today, this car fleet has been almost completely renewed, since these kinds of cars are no longer produced and today are only rarely driven. The presumed changes in accident severity, even in West Germany, at the beginning of the 1990s may adjust to the figures in West Germany, which would have been expected if reunification had not taken place. This is again denoted as changes in the long run.

Hypothesis 2.1: *German reunification leads to a short-run change as well as to a long-run change in the number of fatalities per accident with bodily damages in the West German figures.*

Hypothesis 2.2: *German reunification leads to a short-run change as well as to a long-run change in the number of severely injured persons per accident with bodily damages in the West German figures.*

Hypothesis 2.3: *German reunification leads to a short-run change as well as to a long-run change in the number of lightly injured persons per accident with bodily damages in the West German figures.*

Hypothesis 2.4: *German reunification leads to a short-run change as well as to a long-run change in the ratio of accidents with bodily damages and all accidents in the West German figures.*

4.4.2.2 Unified Germany

The same reasoning as stated above with respect to the situation in West Germany holds regarding the unified Germany. Short-run effects might be more substantial in the East German figures as shown in figure 4.3. Because of programs, which have the goal of improving the infrastructure in the East (BMV,

1992), we suppose that these negative trends adjust to the West German figures, which would have been expected if reunification had not taken place.¹⁸ This supposition is further supported by the modernization of the car fleet in East Germany, which today complies with western safety standards.

Hypothesis 3.1: *German reunification leads to a short-run change as well as to a long-run change in the number of fatalities per accident with bodily damages in the German figures.*

Hypothesis 3.2: *German reunification leads to a short-run change as well as to a long-run change in the number of severely injured persons per accident with bodily damages in the German figures.*

Hypothesis 3.3: *German reunification leads to a short-run change as well as to a long-run change in the number of lightly injured persons per accident with bodily damages in the German figures.*

Hypothesis 3.4: *German reunification leads to a short-run change as well as to a long-run change in the ratio of accidents with bodily damages and all accidents in the German figures.*

¹⁸ Note that an investigation which is based on the risk level in the whole of Germany prior to the event under consideration is impossible because of the missing database in the East (see chapter 4.3).

Chapter 5

Econometric Methodology

Based on the hypotheses stated in the preceding chapter we now present an econometric methodology which is suitable to test these hypotheses. The main idea of our investigation is shown in figure 5.1. There the solid line is the analyzed risk measure. The two events in question are considered to be exogenous events which lead to breaks in the time series.¹ A forecast based on the observations prior to the break would lead to the dotted line. The effect of the exogenous event is, therefore, given by the marked area.

In order to perform a reliable estimation of the quantitative effects (the marked area in figure 5.1), it is necessary for the considered risk measures to follow a stable equilibrium path prior to the event in question. This means that we can reduce the effects to this single event. Our econometric investigation is divided into two parts. First, we estimate equilibrium paths and potentially existing breaks. Then, we estimate the quantitative annual effects.

Our analysis goes as follows. First, we give an introduction to the concept of stationarity in general and its application to our specific case. Second, we suggest a procedure based on dummy variables to estimate the annual effects on various

¹ For convenience, figure 5.1 only refers to a single break T_B . The more complex case of two breaks is considered below.

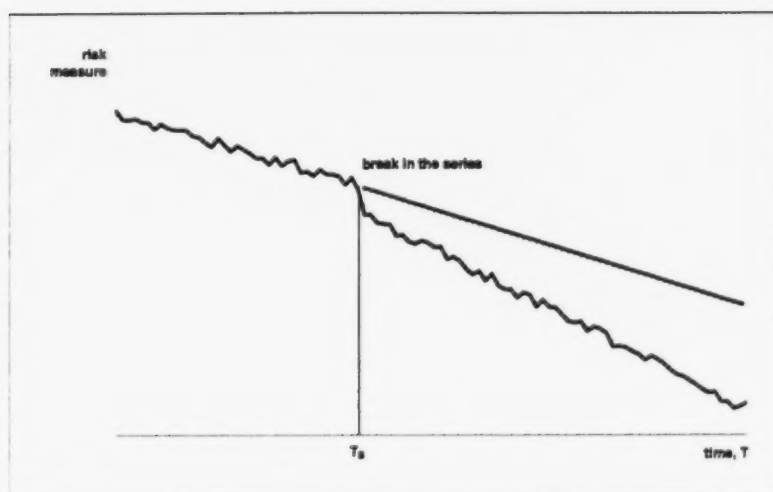


Figure 5.1: Concept of the analysis

risk measures with respect to the two events in question. Third, since the available database restricts the analysis, we will discuss these limits and their consequences within the presented methodology. Fourth, the limits of the investigation are summarized. Finally, based on this methodology we reformulate the hypotheses as stated in chapter 4.4 in a more operational manner.

5.1 Equilibrium Paths, Stationarity, and Breaks

Below we review the concept of stationarity. It is applied in testing whether we can reduce the break in the time series as shown in figure 5.1 to the single event T_B . We analyze whether the series follows an equilibrium path except for the single break in question. Since we are interested in the effects of **two** events, intensified seat belt legislation as well as German reunification, we further have to consider the problem of multiple breaks.

5.1.1 Equilibrium Paths and the Econometric Concept of Stationarity

Stationarity is the econometric pendant for long run equilibrium paths. Its conditions are mentioned by HANSEN (1993, p. 136). The mean as well as the variance have to be constant for all observations y_t . The covariance between two observations y_t and y_{t+k} has to be constant for all t and k .² y_t is constant for all t ; and we can make forecasts for any t . A data generating process of a **stationary process** is given by

$$y_t = \alpha + u_t. \quad (5.1)$$

All y_t alternate around the constant mean α . The innovations u_t are $N(0, \sigma^2)$ distributed.³ The counterpart of such a process is a non-stationary or integrated process. Its data generating process is given by

$$y_t = \alpha + \sum_{i=1}^t u_i. \quad (5.2)$$

The u_t are again $N(0, \sigma^2)$ distributed. If $\alpha = 0$ then y_t equals the sum of all innovations u up to t . Since these processes do not have an equilibrium path in the long run, we speak about **random walks**. Figure 5.2 shows a stationary process, its equilibrium path, and a random walk.

In the case of a random walk $y_{t-1} = \alpha + \sum_{i=1}^{t-1} u_i$ and $y_t = \alpha + \sum_{i=1}^{t-1} u_i + u_t$. Thus, we get

$$y_t = y_{t-1} + u_t. \quad (5.3)$$

² These three conditions lead to a weak stationary process. For convenience, we will only speak about stationarity, even if weak stationarity would be more correct.

³ The process in (5.1) is white noise and, thus, it is even strictly stationary. The assumption of $N(0, \sigma^2)$ distributed residuals is not necessary to generate a (weak) stationary process. A converging process, like ARMA(p,q), is sufficient to fulfill the requirements of weak stationarity (HANSEN, 1993, p. 136). For convenience, we retain this process to explain the concept in general.

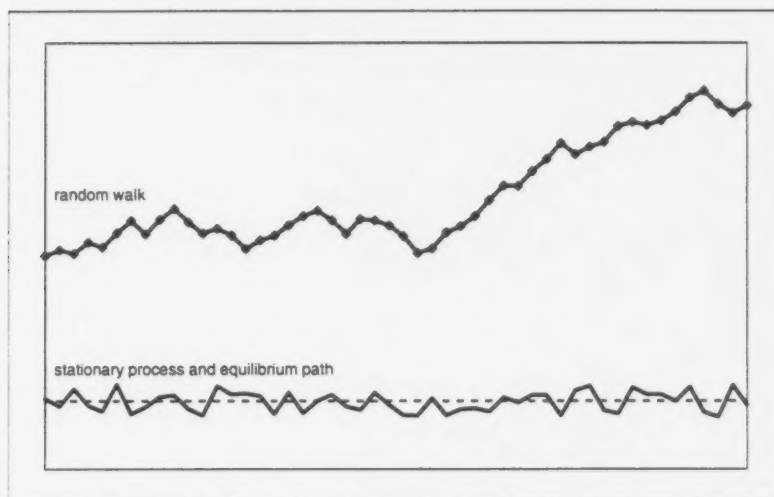


Figure 5.2: Stationary process, equilibrium path, and random walk

The observation in t is fully determined by y_{t-1} , since $E(u_t) = 0$. The best estimator for the observation in $t + 1$ is the observation in t . We can generate such a process step by step as shown in (5.2). We start with $y_1 = \alpha$ and add the innovation u_t in any period t . y_1 is called **unit root** (ENGLE and GRANGER, 1991, chapter 1).

Because of this property of a random walk, namely the determination of y_t by y_{t-1} , we reformulate the properties of a stationary process. In general, there is

$$y_t = \rho y_{t-1} + u_t \quad (5.4)$$

which is a random walk if $\rho = 1$. In turn, it is a stationary autoregressive process of order one, i. e., an **AR(1) process**, if $\rho < 1$.⁴ In the case of a random walk the effect of any innovation u_t is **persistent**, while this effect is **decreasing** in regard to a stationary process. Stationarity, therefore, means that any innovation leads to a deviation from the equilibrium path, but in the long run, i. e., $T \rightarrow \infty$, this deviation becomes zero; the innovation is not persistent and the process returns

⁴ The order of autocorrelation is usually more complex in reality. But in order to explain the main idea of this approach, we keep this structure simple at first.

to its equilibrium path.

Numerous processes are in reality of non-stationary nature. The property of a constant mean is frequently violated since the equilibrium path consists of a positive or negative (linear) time trend. In this case the data generating process is given by

$$y_t = \alpha + \beta t + u_t. \quad (5.5)$$

In this case we speak about a **trend stationary model**.⁵ In contrast, we can also formulate a random walk process with a time dependent component

$$y_t = \alpha + \beta t + \sum_{i=1}^t u_i. \quad (5.6)$$

This process is called **random walk with drift**. In figure 5.3 the differences between both processes are shown and the equilibrium path for the trend stationary model is given.

Again, we can reformulate the model as follows

$$y_t = \rho y_{t-1} + \beta + u_t. \quad (5.7)$$

In the case of a random walk with drift $\rho = 1$. If $\rho < 1$ then the process in (5.7) is trend stationary and autoregressive of order one.

5.1.2 Breaks and Equilibrium Paths

In his 1989 paper PERRON investigated various economic processes for (trend) stationarity. Earlier, conventional methods found the considered processes to

⁵ The property of a constant mean is obviously violated and, thus, we should not speak about stationarity. But now stationarity gets a more general interpretation. The term refers to the equilibrium path rather than to the constant mean. Below we will use the term in this more general interpretation as it was also done by PERRON (1989) and ZIVOT and ANDREWS (1992).

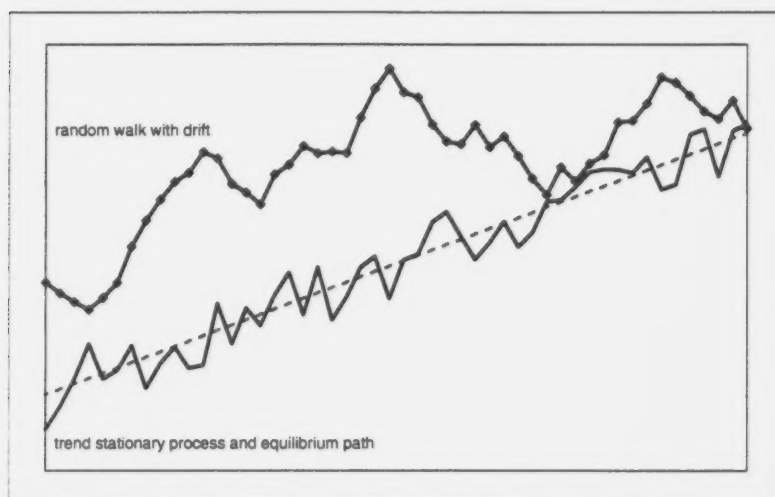


Figure 5.3: Trend stationary process, equilibrium path, and random walk with drift

be non-stationary. PERRON reformulated the processes such that **structural breaks**, interpreted as substantial exogenous events, are taken into account.⁶ He found that they are trend stationary. These processes follow equilibrium paths prior to the event which leads to the breaks in the processes. Due to the break the processes move to other equilibrium paths.⁷

There can occur **breaks of various shapes**, i. e., a break in the constant, a break in the time trend, or a break in both of the components. The data generating

⁶ Examples for such events are the great crash in 1929 and the oil price shock in 1973.

⁷ PERRON's analysis particularly contradicts the results of GRANGER and NEWBOLD (1974) and NELSON and PLOSSER (1982) regarding the same processes.

processes are given by⁸

$$y_t = \alpha_1 + \beta t + (\alpha_2 - \alpha_1)D_\alpha + u_t \quad (5.8a)$$

$$y_t = \alpha + \beta_1 t + (\beta_1 - \beta_2)D_\beta + u_t \quad (5.8b)$$

$$y_t = \alpha_1 + \beta_1 t + (\alpha_2 - \alpha_1)D_\alpha + (\beta_1 - \beta_2)D_\beta + u_t. \quad (5.8c)$$

(5.8a) refers to a model with a break in the constant. There is the dummy variable $D_\alpha = 1$ for $t \geq T_B$,⁹ while T_B is the period when the break occurs. Otherwise D_α equals zero. (5.8b) is a model with a break in the time trend. There is the dummy variable $D_\beta = t - T_B$ for $t \geq T_B$ and zero otherwise. (5.8c) is a model with a break in the constant as well as in the time trend. There the same holds for the dummies D_α and D_β as in (5.8a) and (5.8b), respectively.¹⁰ In our investigation breaks in both parameters are considered because of the potentially occurring adjustment processes after the break.

PERRON's method is suitable in order to estimate effects of exogenous events leading to structural breaks in time series. Testing for equilibrium paths by applying conventional methods may lead to the rejection of a stationarity hypothesis, i. e., we only find random walks. The explicit modeling of a structural break, in contrast, may yield to a (trend) stationary process, i. e., the considered series follows equilibrium paths before and after this break. If the latter holds we can estimate the quantitative effects of this break (see figure 5.1, p. 52) and attribute them to the considered event.

⁸ The model in question consists of an intercept α (or α_1) and an overall time trend β (or β_1). If we look for stationarity we have in mind trend stationarity or trend stationarity with a break.

⁹ As we will see below, $t = T_B$ has to be included in our models. Breaks occur at the beginning of the considered month.

¹⁰ A similar model was suggested by LOEB (1993; 1995). He could only find general effects with respect to seat belt legislation since he introduced only one additional dummy variable beside the seasonal adjustment. He did not evaluate the shape of the break and assumed a break in constant only. Furthermore, he did not test for equilibrium paths. Hence, his results might be biased by other events than those considered.

5.1.3 Multiple Breaks

According to PERRON's approach a random walk as given in (5.3) consists of T breaks. We would have to model a break in every period in order to reduce it to stationarity which is, of course, nonsense. In reality we do not know whether an observed process originates from a random walk or from a (trend) stationary process, since we can only judge (or test) this property given the available sample. In empirical investigations we can either make assumptions about the underlying data generating process, or we can test hypotheses about this process. If the latter is adopted then a theory should be reflected by the corresponding properties of the observed sample. This is also the topic of our investigation, since our theory supposes trend stationarity with structural break, which might be confirmed or rejected by the properties of the analyzed processes.

Structural breaks are similar to the innovations of a random walk as shown in (5.3), since they persist in the long run. Because of their property that they can be theoretically determined, they may reduce an apparent random walk to a (trend) stationary process. The basic assumption in our investigation, therefore, is (trend) stationarity. The main objective consists of the **identification of all relevant breaks**. Doing this we can reduce any apparent random walk to a (trend) stationary process. This will succeed without any failures if we model a sufficient number of breaks. Of course, it quickly becomes uninterpretable when this number exceeds two or three. For this reason an additional requirement in our investigation is the **determination of a parsimonious model**. The number of breaks should be as small as possible. Given this requirement our theory consists of two breaks, namely the changing seat belt legislation in 1984 and German reunification in 1990.

If we do not consider all the occurring breaks the estimation of quantitative effects of a specific break will be biased. If two breaks in T_{B2} as well as in T_{B1} occur the equilibrium path will be changed twice. This has to be considered if we are interested in the effects after T_{B2} (see figure 5.4). The non-consideration of T_{B1} leads to an increasing overall time trend (the increasing dotted line), but we are interested in the effects given by the marked region. The case is more problematic

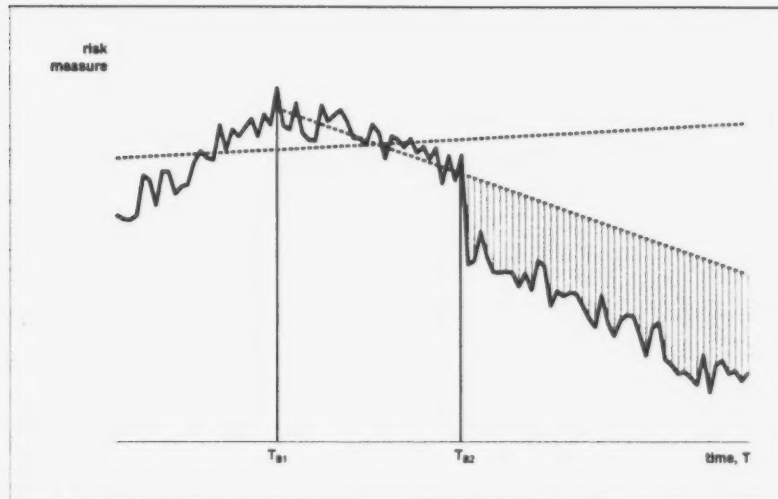


Figure 5.4: Equilibrium path and multiple breaks

if we are interested in the effects after T_{B1} instead of those after T_{B2} . In this case it might be hard to distinguish between the effects coming from the first break and those coming from the second break. In general, the first break can (partly) compensate or reinforce the effects of the second break.

5.1.4 Testing Stationarity and Structural Breaks

There are various procedures established to test stationarity in time series. Below we will apply the augmented DICKEY-FULLER test (ADF test). It was also the basis for testing stationarity with structural breaks as done by PERRON (1989). The ADF test is based on the DF test by FULLER (1976) and DICKEY and FULLER (1979; 1981). Some advancements of the test procedure were stated by SAID and DICKEY (1984).¹¹ As shown in (5.3) y_t originates from a random walk process if y_t is determined by its prior observation y_{t-1} , therefore, we have to test whether ρ equals one or not.

¹¹ Another procedure called the PHILLIPS-PERRON test was suggested by PHILLIPS and PERRON (1988).

In reality the u_t are not $N(0, \sigma^2)$ distributed, i. e., they are not white noise. The estimator $\hat{\rho}$ is unbiased, but it is, however, inefficient (see, e. g., ASSENMACHER, 1991, pp. 149, or VON AUER, 1999, pp. 288). There are usually more complex lag structures of the form

$$u_t = \sum_{i=1}^p \rho_i u_{t-i} + \sum_{j=1}^q \theta_j \varepsilon_{t-j} + \varepsilon_t. \quad (5.9)$$

This ARMA(p,q) model contains $N(0, \sigma^2)$ distributed residuals ε_t . In (5.9) we have to test whether the AR(p) process has one or more unit roots. In this case we can reformulate (5.9) as a (non-stationary) ARIMA(p,d,q) process with d unit roots. We have to compute first differences d times repeated to get a (stationary) ARMA(p,q) model. The ADF test can also identify unit roots in such complex structures.

A complete formulation of (5.9) depends on p and q , but we usually do not know these parameters. Early approaches of the unit root test were based on the assumption that either p and q are known or that q equals zero (DICKEY and FULLER, 1979). In case of the ADF test (5.9) the procedure is somewhat simplified. The ARMA(p,q) is approximated by a AR(p') model (SAID and DICKEY, 1984). This is possible in any desired precision if p' is chosen sufficiently high. The basic test equation including a constant and a time dependent component is given by

$$\Delta y_t = \alpha + \beta_0 t + \beta_1 y_{t-1} + \sum_{i=1}^p \rho_i \Delta y_{t-i} + \varepsilon_t. \quad (5.10)$$

There the null hypothesis of non-stationarity, i. e., $\beta_1 = 0$, is tested against the alternative hypothesis of (trend) stationarity. The t -statistics are usually applied to judge whether the estimated coefficient is significantly different from zero. In the case of (5.10) the standard t distribution cannot be applied, since lagged values of the endogenous variable are included in the model. For this reason MACKINNON (1991) computed corrected critical values which we will use below.

The test procedure has three degrees of freedom, a constant α , a time dependent

component $\beta_0 t$, and the parameter p to specify the autocorrelation structure. The first two parameters α and $\beta_0 t$ are less problematic. If we include a time dependent component in the test we can distinguish between a trend stationary model and a random walk process with drift. Since this component is completely unknown, the parameter p is more problematic. SAID and DICKEY (1984) suggested the following method to approximate p .

$$p = k \sqrt[p]{T}. \quad (5.11)$$

The parameter k is not explicitly given (see also PAGAN and WICKENS, 1989). SCHWERT (1987) suggested a formula to compute p which is similar to that given by SAID and DICKEY.

$$p = \text{int} \left(12 \sqrt[p]{T} \right). \quad (5.12)$$

int computes the integer of the expression in parentheses. The factor 12 is applied in the case of monthly observations. There also exists a method based on the AKAIKE information criterion (AIC) given by

$$AIC = \ln \sigma_e^2 + \frac{2}{T} p. \quad (5.13)$$

The AIC depends on the estimated variance of the residuals in the test regression. The lag structure p is accepted as soon as AIC becomes minimal (HARTUNG, 1989, p. 687). PERRON (1989) suggested the following procedure to identify p . He repeated the ADF test with increasing p as long as the t -statistic of the parameter of the last added lagged value was less than 1.60. This test was rejected and the test prior to the rejected one was accepted. This procedure and the critical value of 1.60 make sure that the lag structure was properly modeled.

In general, p is an increasing function of T , the number of observations in the series. All of the procedures to compute p have disadvantages. Either we use an uncertain lag structure (SCHWERT, 1987) or we have to repeat the test frequently to get a proper formulation (AIC and PERRON, 1989). The more complex the lag structure (increasing p) the more probable is the non-rejection of H_0 , which

means that the non-stationarity of the model cannot be rejected. In other words, we would accept the possibly wrong hypothesis of stationarity by a insufficiently modeled p . We should, therefore, use a more complex lag structure which makes sure that we do not wrongly classify a random walk as (trend) stationary (see, e. g., GERDTHAM and LÖTHGREN, 1999).

The procedure for testing stationarity under a structural break as suggested by PERRON (1989) is based on the ADF test as shown in (5.10). Prior to the ADF procedure a further test is applied to see which shape of the break occurs. This is done using a simple OLS regression with a break in the supposed period.¹² These regressions are given by (5.8). Since an overall constant as well as an overall time trend are already included in these OLS regressions, the subsequent ADF test is specified without these components.

$$\Delta y_t = \beta_1 y_{t-1} + \sum_{i=1}^p \rho_i \Delta y_{t-i} + \varepsilon_t. \quad (5.14)$$

The formulation of the lag structure is the same as in the procedure mentioned above, i. e., there are three opportunities to specify p . PERRON (1989) computed critical values for the t -statistic of β_1 in (5.14) depending on the shape of the break and on λ , the date of the break relative to the total sample size ($\lambda = T_B/T$).

5.1.5 Application

5.1.5.1 Time Series and Test Procedures

Below we apply stationarity tests in a specific way. First, the series will be seasonally adjusted based on a multiplicative moving average method.¹³ We

¹² ZIVOT and ANDREWS (1992) suggested a procedure very similar to that by PERRON (1989). There the date of the break was endogenously estimated.

¹³ Since the series have a strong seasonal component because of various reasons, e. g., changing weather conditions, we adjust for this component. In tests for stationarity we are interested in the long memory of a series, while the seasonal component is short memory in this interpretation (see ENGLE and GRANGER, 1991, chapter 1).

compute a moving average covering a whole year. Then we calculate the ratio of the series to the moving average which will be averaged over all years in the current sample for each month separately. Second, we compute the natural logs of each series as was also done by PERRON (1989), WAGENAAR ET AL. (1988), and LOEB (1993; 1995).

In order to test for stationarity with a structural break we apply PERRON's test procedure in a somewhat different manner as stated in his 1989 paper. Since his investigation was based on yearly series, he got p values ranging from 1 to 8 which would not lead to proper formulations of our models. In order to make sure that we get a proper formulation of p and a sufficient value in any scenario, we set $p_{max} = 20$. This particularly holds if we analyze monthly observations. p_{max} decreases step by step as long as we get a t -statistic of the last added lag which exceeds 1.60; this p value is then adopted. A more complex lag structure increases the probability that we keep non-stationarity instead of a (wrong) adoption of (trend) stationarity (GERDTHAM and LÖTHGREN, 1999). We must be careful before accepting (trend) stationarity (with structural break) which is required to estimate quantitative effects.

5.1.5.2 No Break, Single Break, and Multiple Breaks

The test procedure for any risk measure or series goes as follows. First, we test for stationarity without structural breaks. It might be that the exogenous events in question do not have any effect on the considered risk measure. Thus, we are looking for a single equilibrium path for the whole sample. Second, we test for a single break in the series and, thus, we assume that only one of the events in question affects the considered series. If we only find a single break we can simply estimate its effects. Third, we test for multiple breaks, i. e., both events in question affect the risk measure. Since we cannot test for multiple breaks using the procedure mentioned above, we divide our sample into two fractions and investigate both for a single break (see figure 5.4). The first fraction starts in $t = 0$ and ends in $t = T_{B2} - 1$. In this section we test for a break in $t = T_{B1}$. The second fraction ranges from $t = T_{B1} + 1$ to $t = T_N$, i. e., it contains all

Table 5.1: Multiple breaks and estimated effects

	computable effects of...	period
$B_1 \wedge B_2$	B_1	$[B_1, B_2]$
	B_2 given B_1	$[B_2, T]$
B_1 only	B_1	$[B_1, B_2]$
B_2 only	B_2 given equilibrium path B_1, B_2	$[B_2, T]$
neither B_1 nor B_2	no computable effects/biased effects	

observations between the first break and the end of the sample. There we are looking for a break in $t = T_{B2}$. If we test for multiple breaks various scenarios may occur which are shown in table 5.1.

The last case in table 5.1 should be discussed more precisely. Given this case two scenarios may arise. First, we may not find any stable equilibrium path prior to a break which would make a valid modelling of the break in question impossible in our methodology. Second, we may find a stable equilibrium path prior to a break, but the series is not (trend) stationary after the break. Then we can model the break and estimate absolute effects. We have to keep in mind that these effects do not exclusively originate from the event in question.

5.1.5.3 Breaks in the Time Trend and Risk Adjustment

Breaks in the time trend serve as an indicator for long-term adjustments of the series to their level prior to the potentially occurred break in the constant. In order to achieve such an adjustment a negative break in the absolute term has to be accompanied by a positive break in time trend and vice versa.

This conclusion appears to be somewhat inconsistent with the findings mentioned above. There we argued that structural breaks are of a persistent nature. This problem might be attributed to the data generating process and, thus, to the observed fraction of the time series. In our limited domain of road traffic we do not know how long such potentially occurring adjustment processes last. We are

not sure whether they are already covered by the observed sample.

Non-persistent breaks in time series, which means that they are disappear in the long run, can only be modeled by a stationary process if the analyzed sample is of sufficient size. In this case the sample also covers the process of adjustment of any complex structure. Compared to the extents of the modeled breaks our sample may be of small size. It may not cover the complete adjustment process after a structural break. The applied methodology may not be able to detect (trend) stationarity if the adjustment process is too complex in nature, i. e., if it exceeds the observed sample size. In this case corresponding breaks in constant as well as in time trend may at the very least serve as an indicator of adjustment processes, even if we cannot be completely sure whether this is the true conclusion. This is, however, a problem in any empirical investigation. These breaks are the best indicators we can get.

5.2 Estimating Safety Effects Using Dummy Variables

5.2.1 A Simple Linear Model

A simple OLS-based method in analyzing the evidence of breaks in time series is proposed below. Given T_B , the expected date of the break, the procedure goes as follows.¹⁴ The long-term time dependent path assuming no break would be

$$y_t = \alpha + \beta t + u_t \quad (5.15)$$

The deviations caused by the break are computed by including a set of dummy

¹⁴ For simplicity we assume that only one break occurs in the considered series. If the ADF test finds that both events in question significantly affect the series, then we divide the sample into two parts as shown in chapter 5.1.3.

variables

$$y_t = \alpha + \beta t + \sum_{i=T_B}^T \gamma_i \delta_{i,t} + u_t \quad (5.16)$$

where the dummies $\delta_{i,t}$ for any observation after T_B are given by

$$\delta_{t,i} = \begin{cases} 1 & \text{if } t = i \\ 0 & \text{if } t \neq i \end{cases}$$

$\hat{\gamma}_i$ is the estimated effect of the break in absolute values for any observation $t \geq T_B$.

The problem of (5.16) is that it describes monthly effects, since monthly observations are considered. For a long-term analysis it is more meaningful to compute the average yearly effect which is 1/12 of the cumulated monthly effects. It is given as follows

$$\sum_{s=1}^{12} \gamma_s \delta_{s,t} = \sum_{s=1}^{12} (\gamma_s - \gamma_A) \delta_{s,t} + \gamma_A \sum_{s=1}^{12} \delta_{s,t} \quad (5.17)$$

$\hat{\gamma}_s$ is the estimator of the monthly deviations in any month s in year A , while $\hat{\gamma}_A$ is the corresponding estimator of the average yearly deviations. The right-hand side of equation (5.17) results from a simple expansion of the left-hand side by the addition and simultaneously the subtraction of $\gamma_A \sum_{s=1}^{12} \delta_{s,t}$. Replacing $\gamma_s - \gamma_A$ by γ'_s and $\sum_{s=1}^{12} \delta_{s,t}$ by $\delta_{A,t}$ we get

$$\sum_{s=1}^{12} \gamma_s \delta_{s,t} = \gamma_A \delta_{A,t} + \sum_{s=1}^{12} \gamma'_s \delta_{s,t} \quad (5.18)$$

$\delta_{A,t}$ equals 1 if the observation in t belongs to year A and zero otherwise. There are 12 different dummy variables $\delta_{s,t}$ covering the 12 months of the year. Thus,

we have to include the following restriction

$$\sum_{s=1}^{12} \gamma'_s = 0 \quad (5.19a)$$

$$\gamma'_{12} = - \sum_{s=1}^{11} \gamma'_s \quad (5.19b)$$

We get

$$\sum_{s=1}^{12} \gamma_s \delta_{s,t} = \gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_s \delta_{s,t} + \gamma'_{12} \delta_{12,t} \quad (5.20a)$$

$$= \gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_s \delta_{s,t} - \left(\sum_{s=1}^{11} \gamma'_s \right) \delta_{12,t} \quad (5.20b)$$

$$= \gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_s (\delta_{s,t} - \delta_{12,t}) \quad (5.20c)$$

The dummy variable $\delta'_{s,t} = \delta_{s,t} - \delta_{12,t}$ is defined as

$$\delta'_{s,t} = \begin{cases} 1 & \text{if } t \text{ equals month } s \text{ and } t \text{ belongs to year } A \\ -1 & \text{if } t = 12 \text{ and } t \text{ belongs to year } A \\ 0 & \text{otherwise} \end{cases}$$

Since we want to calculate average yearly deviations regarding one calendar year, though the break does not necessarily occur at the beginning of the year, the number of included dummies is given as follows: in all cases we include A dummy variables covering the yearly deviations. The number of the monthly dummies $\delta'_{s,t}$ equals $12(A-2)$, i. e., the fully covered years, plus the number of the months after T_B in the year where the break occurs, plus the number of the months in the last year considered.

Of particular interest are the average yearly effects γ_A . We can reformulate the

sum in (5.16) as follows

$$\sum_{i=T_B}^T \gamma_i \delta_{i,t} = \sum_A \left(\gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_{s,A} \delta'_{s,A,t} \right) \quad (5.21)$$

and, thus, we get the reformulation of (5.16) as

$$y_t = \alpha + \beta t + \sum_A \left(\gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_{s,A} \delta'_{s,A,t} \right) + u_t \quad (5.22)$$

Equation (5.22) describes the major effects assumed. It does not refer to seasonal fluctuations even though the analyzed risk measures in traffic safety may have a strong seasonal component, e. g., because of weather dependent influences (see also chapter 5.1). Because of the analyzed monthly observations, we have to add 11 seasonal dummy variables

$$y_t = \alpha + \beta t + \sum_A \left(\gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_{s,A} \delta'_{s,A,t} \right) + \sum_{m=1}^{11} \sigma_m \Delta_{m,t} + u_t \quad (5.23)$$

$\Delta_{m,t}$ equals 1 in month m in every year and zero otherwise. $\hat{\sigma}_m$ is the estimator for the seasonal influence of month m .

5.2.2 Testing Autocorrelation

Since (5.23) probably does not represent the complete relationship of y_t and its explanatory variables, the residuals u_t are not white noise. We have to adjust

them by including an ARMA(p,q) process which leads to

$$\begin{aligned}
 y_t = & \alpha + \beta t + \sum_A \left(\gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_{s,A} \delta'_{s,A,t} \right) \\
 & + \sum_{m=1}^{11} \sigma_m \Delta_{m,t} \\
 & + \sum_{k=1}^p \rho_k y_{t-k} + \sum_{l=1}^q \theta_l \varepsilon_{t-l} + \varepsilon_t
 \end{aligned} \tag{5.24}$$

ε_t is white noise, which has to be tested by an adequate test procedure. A well known and quite simple method testing autocorrelation in the residuals is the DURBIN-WATSON test (DW or d test, see DURBIN and WATSON, 1950; 1951). Its method can be found in any basic textbook in econometrics (see, e. g., JOHNSTON, 1984; HARTUNG, 1989; GRIFFITH ET AL., 1993; VON AUER, 1999). Despite its frequent application, the DW test has two disadvantages. First, it only tests for first order autocorrelation; if higher orders of autocorrelation occur, the test fails. Second, it is only applicable in those cases where no lagged values of the dependent variable appear in the estimation.

Because of these disadvantages we will instead apply the BREUSCH-GODFREY serial correlation LM test which allows the test of autocorrelation of higher orders than one (see, e. g., JOHNSTON, 1984). Depending on the test results we select the values for p and q in (5.24) whereas the formulation of ARMA(p,q) should be as parsimonious as possible.

The null hypothesis is

$$H_0 : \quad \varepsilon \sim N(0, \sigma_\varepsilon^2)$$

It is tested against the two alternative hypotheses that (a) a remaining AR process exists and that (b) a remaining MA process exists. It is not possible to test which of these alternative hypotheses is true. In a sufficiently formulated OLS estimation the null hypothesis should not be rejected. The accepted model is based on a non-rejection of the null hypothesis which may appear to be a quite

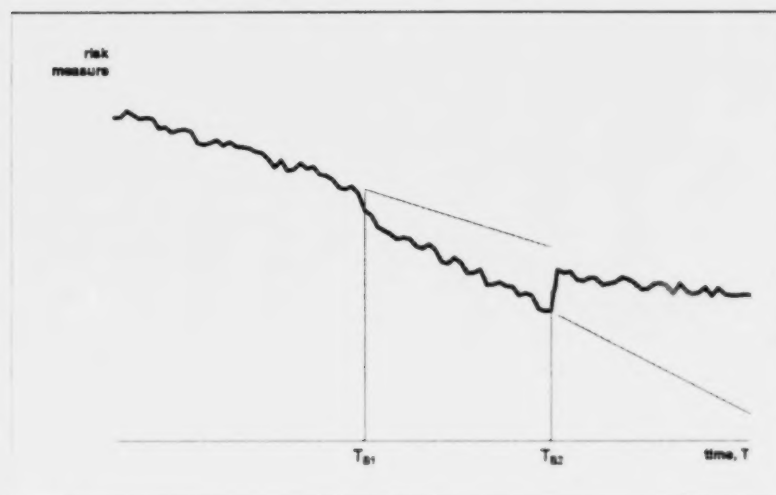


Figure 5.5: Quantitative effects of the two events in $t = T_{B1}$ and in $t = T_{B2}$

poor result. Nevertheless, it is much better than a completely wrong formulated model based on the DW test.

In the BREUSCH-GODFREY test the residuals ε_t of the OLS estimation are regressed on their lagged values $\varepsilon_{t-1}, \dots, \varepsilon_{t-p}$, and on all K exogenous variables $x_{j,t}$ ($j = 1, \dots, K$) in (5.24), where p is the order of presumed autocorrelation of the residuals. The computed R^2 value of this test regression has to be multiplied by n , the number of observations included in the OLS regression, to get the test statistic l which is $\chi^2(p)$ distributed. The null hypothesis of no autocorrelation in the residuals in (5.24) is not rejected if a significantly large value of l is found.

5.2.3 Application

Since we are investigating two potential breaks, we have to make some limitations given the methodology just mentioned. The effects of the second event in question always occur given the effects of the first one. We cannot distinguish between consequences of both events when the second has occurred. In other words, the second event may (partially) compensate or reinforce the effects of the first. For

this reason we split our sample into two parts as shown in figure 5.5. Then we can estimate the effects of the first event in sample $(0, T_{B1})$ and of the second in sample (T_{B1}, T) given the break in T_{B1} . With respect to the latter we have additionally to specify T_{B1} in (5.24) by the term $\alpha_1 D_\alpha + \beta_1 D_\beta$, where $D_\alpha = 1$ and $D_\beta = t - T_{B1}$ if $t \geq T_{B1}$. Otherwise both variables would equal zero.

$$\begin{aligned}
 y_t = & \alpha + \beta t + \alpha_1 D_\alpha + \beta_1 D_\beta \\
 & + \sum_A \left(\gamma_A \delta_{A,t} + \sum_{s=1}^{11} \gamma'_{s,A} \delta'_{s,A,t} \right) \\
 & + \sum_{m=1}^{11} \sigma_m \Delta_{m,t} \\
 & + \sum_{k=1}^p \rho_k y_{t-k} + \sum_{l=1}^q \theta_l \varepsilon_{t-l} + \varepsilon_t
 \end{aligned}$$

5.3 Break Points and Available Database

The applied methodology in the analysis of stationarity with structural breaks is based on exogenously determined breaks. Regarding the intensified seat belt legislation the determination of this break is less problematic, since the corresponding law came into effect on August 1, 1984; we will adopt this date for the first break in question.

German reunification poses some problems, since it was a process rather than a single event. When investigating its effects on traffic safety, we have various possibilities to select as the date of the break:

1. November 9, 1989, the date the border between both parts of Germany was opened,
2. July 1, 1990, the date German Mark became official currency in East Germany,
3. October 3, 1990, the date German reunification was fulfilled,

4. January 1, 1991, the date when we started to collect relevant data for West as well as for East Germany.

The first, third, and fourth date are arbitrary, since they do not relate to economic events. From an economic point of view the second date appears to be the most preferable. The introduction of German Mark as the official currency in the East gives the opportunity to the East Germans to demand goods in the West, e. g., fuel and road traffic. For this reason we adopt July 1, 1990, as the date of the break in our analysis of West German figures and German reunification.

As mentioned in chapter 4.3 we will compare figures of the reunified Germany to the West German figures before the reunification in order to analyze the effects of this event in Germany. Therefore, July 1, 1990, cannot be adopted as the date of the break. Valid German figures did not exist between July and December, 1990. Since West German figures end in December, 1990, and figures of the reunified Germany start in January, 1991, January 1, 1990, is an explicit break in the database. Even if it is unfavorable in terms of economics, better figures are not available and, therefore, we have to think about the consequences.

If we observe a break in West German figures in July, 1990, then we will have to model three breaks: the seat belt legislation in August, 1984, German reunification (introduction of German Mark as the currency in the East) in July, 1990, and German reunification (changing structure in database) in January, 1991. Since the second and the third break are very close, the ADF test will not distinguish between each of them. We can further expect that the break in July, 1990, in the West German figures is much less substantial than that in the data structure in January, 1991 (see figures 4.4, p. 41 and 4.5, p. 42). We, therefore, adopt January 1, 1991, the break given by the data structure, when we compare figures of the reunified Germany to the West German figures before this event.

5.4 Operational Hypotheses

In chapter 4.4 the formulation of the hypotheses was derived from the theoretical background. Combined with the econometric methodology introduced above we can reformulate these hypotheses in an operational manner.

5.4.1 The Intensified Seat Belt Legislation

Hypothesis R1.1: *The intensified seat belt legislation leads to a shift in the constant as well as in the overall time trend in the number of fatalities per accident with bodily damages.*

Hypothesis R1.2: *The intensified seat belt legislation leads to a shift in the constant as well as in the overall time trend in the number of severely injured persons per accident with bodily damages.*

Hypothesis R1.3: *The intensified seat belt legislation leads to a shift in the constant as well as in the overall time trend in the number of lightly injured persons per accident with bodily damages.*

Hypothesis R1.4: *The intensified seat belt legislation leads to a shift in the constant as well as in the overall time trend in the ratio of accidents with bodily damages and the accidents with material damages.*

Hypothesis R1.5: *The intensified seat belt legislation leads to a shift in the constant as well as in the overall time trend in the accident frequency.*

5.4.2 German Reunification

West Germany

Hypothesis R2.1: *With respect to the West German series German reunification leads to a shift in the constant as well as in the overall time trend in the number of fatalities per accident with bodily damages.*

Hypothesis R2.2: *With respect to the West German series German reunification leads to a shift in the constant as well as in the overall time trend in the number of severely injured persons per accident with bodily damages.*

Hypothesis R2.3: *With respect to the West German series German reunification leads to a shift in the constant as well as in the overall time trend in the number of lightly injured persons per accident with bodily damages.*

Hypothesis R2.4: *With respect to the West German series German reunification leads to a shift in the constant as well as in the overall time trend in the ratio of accidents with bodily damages and all accidents.*

Unified Germany

Hypothesis R3.1: *With respect to the series of the unified Germany German reunification leads to a shift in the constant as well as in the overall time trend in the number of fatalities per accident with bodily damages.*

Hypothesis R3.2: *With respect to the series of the unified Germany German reunification leads to a shift in the constant as well as in the overall time trend in the number of severely injured persons per accident with bodily damages.*

Hypothesis R3.3: *With respect to the series of the unified Germany German reunification leads to a shift in the constant as well as in the overall time trend in the number of lightly injured persons per accident with bodily damages.*

Hypothesis R3.4: *With respect to the series of the unified Germany German reunification leads to a shift in the constant as well as in the overall time trend in the ratio of accidents with bodily damages and all accidents.*

Chapter 6

Empirical Results: Intensified Seat Belt Legislation

The presentation of the empirical results is organized as follows. With respect to the intensified seat belt legislation we analyze the sub-sample starting in January, 1968, and lasting until June, 1990. In this period only the West German series are considered (see chapter 4.3). The break in the time series is August, 1984, the time that the law came into effect (see chapter 5.3). We firstly apply simple ADF tests to any West German series starting in January, 1968, and lasting until December, 1998.¹ If a structural break is found we will compute the deviations from the equilibrium path. Finally, we will draw some conclusions from these empirical results.

¹ If the test confirms a stationary model in the period from January, 1968, until December, 1998, without any break, this has to be taken into account when we investigate the effects of German reunification in chapter 7. In this case neither the intensified seat belt legislation nor the reunification will affect the considered risk measure.

6.1 Fatalities per Accident with Bodily Damages

The simple ADF test without structural break in the time series of the fatalities per accident with bodily damages does not reject non-stationarity in the period from January, 1968, to December, 1998 (see table 6.1).

At least one structural break occurs in the series. Thus, we come back to the sub-sample of the West German series observed from January, 1968, to June, 1990. The results of the ADF test without structural break are shown in table 6.2. In the test non-stationarity is rejected by two of the three applied methods. Only the PERRON procedure fails. In this case the number of included lags of $p = 10$ improperly models the lag structure given the other p values. We should have in mind that the larger the p the less probable is the rejection of non-stationarity (GERDTHAM and LÖTHGREN, 1999). A more complex lag structure should reject stationarity which is, however, not the case. So we can conclude that the series follows a decreasing equilibrium path with no additional breaks.

In light of this result the estimation of absolute effects using dummy variables would not make any sense. Thus, we terminate this empirical investigation. A structural break in the West German series due to intensified seat belt legislation

Table 6.1: ADF test (no break), fatalities per accident with bodily damages, West German series (sample: 01/1968-12/1998)

	PERRON	AIC	SCHWERT
constant	0.5799**	0.6246**	0.5842**
trend	-0.0005**	-0.0005**	-0.0005**
ADF ^a	-2.4856	-2.5524	-2.4716
p^b	15	19	16

** significant at 5% level

^a t statistic of estimated parameter ν_{k-1} in ADF test

^b number of included lags in ADF test

Table 6.2: ADF test (no break), fatalities per accident with bodily damages, West German series (sample: 01/1968-06/1990)

	PERRON	AIC	SCHWERT
constant	0.9763**	1.4199**	1.3568**
trend	-0.0009**	-0.0013**	-0.0012**
ADF ^a	-3.0045	-4.0509***	-3.7516**
p^b	10	14	15

/ significant at 5/1% level

^a t statistic of estimated parameter γ_{t-1} in ADF test

^b number of included lags in ADF test

cannot be found with respect to fatalities per accident with bodily damages. Hypothesis 1.1 has to be rejected.

6.2 Severely Injured Persons per Accident with Bodily Damages

First, we perform an ADF test without any break in the West German series observed from January, 1968, until December, 1998. The results are stated in table 6.3. Non-stationarity without a structural break cannot be rejected. Thus, we come back to the sub-sample in the period from January, 1968, to June, 1990, in which case the ADF test rejects non-stationarity. We adopt a single structural break in the constant as well as in the time trend in August, 1984 (see table 6.4). The risk measure follows an equilibrium path until August, 1984, and moves to another one after this date. Because of the negative sign of the the break in the time trend, the former decreasing equilibrium path becomes steeper.

The estimated quantitative effects confirm our above-stated results (see table 6.5). The safety effects in West Germany increase continuously between 1984 and 1990. These results make possible the conclusion that no adjustment exists

Table 6.3: ADF test (no break), number of severely injured persons per accident with bodily damages, West German series (sample: 01/1968-12/1998)

	PERRON	AIC	SCHWERT
constant	0.4915**	0.4400**	0.4915**
trend	-0.0001**	-0.0001**	-0.0001**
ADF ^a	-2.2249	-1.9613	-2.2249
p^b	16	18	16

** significant at 5% level

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

Table 6.4: ADF test (break in 08/1984), number of severely injured persons per accident with bodily damages, West German series (sample: 01/1968-06/1990)

	parameter	ADF ^a	p^b
constant	6.0987**		
trend	-0.0008**		
break. const.	-0.0439**		
break. trend	-0.0016**		
PERRON		-4.63**	15
AIC		-3.97*	18
SCHWERT		-4.63**	15

*/** significant at 10/5% level

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

in the former time frame. The results can be summarized as follows. Intensified seat belt legislation leads to a sudden decrease in the number of severely injured persons per accident with bodily damages. In the long run these effects even increase. Hypothesis 1.2 is not rejected.

Table 6.5: Deviations from the equilibrium path (1984-1990), number of severely injured persons per 1,000 accidents with bodily damages, West German series (sample: 01/1968-06/1990)

	parameter	t statistic
constant	446.42	(129.15)
trend	-0.36	(-14.67)
1984	-14.00	(-2.37)
1985	-19.04	(-3.40)
1986	-22.59	(-3.97)
1987	-29.27	(-5.01)
1988	-34.58	(-5.74)
1989	-40.44	(-6.54)
1990	-44.99	(-6.28)
ARMA(p,q)	7,0	

6.3 Lightly Injured Persons per Accident with Bodily Damages

First, stationarity is tested for this risk measure. The results of the ADF test without structural break for the sample observed from January, 1968, to December, 1998, are shown in table 6.6. Non-stationarity is not rejected. Thus, we come back to the sub-sample from January, 1968, until June, 1990. We find an equilibrium path with structural break in the constant as well as in the time trend (see table 6.7). The break in the constant is marginally positive, while the likewise positive break in the time trend substantially exceeds the former overall time trend.

After testing for stationarity the quantitative effects are analyzed. The estimation of deviations in absolute numbers confirms the above-stated results (see

Table 6.6: ADF test (no break), number of lightly injured persons per accident with bodily damages, West German series (sample: 01/1968-12/1998)

	PERRON	AIC	SCHWERT
constant	0.2233	0.2170	0.2257
trend	-0.00002**	-0.00003**	-0.00003**
ADF ^a	-1.1648	-1.1146	-1.1697
p^b	15	18	16

** significant at 5% level

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

Table 6.7: ADF test (break in 08/1984), number of lightly injured persons per accident with bodily damages, West German Series (sample: 01/1968-06/1990)

	parameter	ADF ^a	p^b
constant	6.8693**		
trend	-0.0002**		
break. const.	0.0115**		
break. trend	0.0015**		
PERRON		-4.14*	15
AIC		-3.86*	17
SCHWERT		-4.14*	15

*/** significant at 10/5% level

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

table 6.8). After the intensified seat belt legislation the suddenly occurring effects even increase between 1984 and 1990. Thus, the empirical findings can be combined to give the following result. After the intensification of the seat belt legislation we find a sudden increase in the number of lightly injured persons per accident with bodily damages. The effects do not decrease in the long run. Hypothesis 1.3 is not rejected.

Table 6.8: Deviations from the equilibrium path (1984-1990), number of lightly injured persons per 1,000 accidents with bodily damages, West German series (sample: 01/1968-06/1990)

	parameter	<i>t</i> statistic
constant	957.81	(159.12)
trend	-0.25	(-6.02)
1984	16.97	(1.47)
1985	24.85	(2.52)
1986	43.01	(4.26)
1987	65.39	(6.32)
1988	82.94	(7.80)
1989	93.42	(8.58)
1990	110.76	(8.44)
ARMA(p,q)	3.1	

6.4 Ratio Between Accidents with Bodily Damages and All Types of Accidents

The results of the ADF test without a structural break in the sample from January, 1968, until December, 1998, are shown in table 6.9. As can be seen the non-stationarity hypothesis cannot be rejected. Even if we consider the subsample from January, 1968, until June, 1990, with a structural break in August, 1984, the non-stationarity hypotheses is not rejected (see table 6.10).

As shown in figure 6.1 no stable equilibrium path with a structural break in August, 1984, can be found in the number of lightly injured persons per accident with bodily damages.² Even if the modeled break in August, 1984, appears to be

² The graph in figure 6.1 is based on a simple OLS regression where the residuals are not adjusted. The estimation equals the first step in the procedure testing stationarity with

Table 6.9: ADF test (no break), ratio between accidents with bodily damages and all types of accidents, West German series (sample: 01/1968-12/1998)

	PERRON	AIC	SCHWERT
constant	0.3364	0.3260	0.4420
trend	-0.00007	-0.00008	-0.0001
ADF ^a	-1.1620	-1.1492	-1.4925
p^b	14	13	16

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

Table 6.10: ADF test (break in 08/1984), ratio between accidents with bodily damages and all types of accidents, West German series (sample: 01/1968-06/1990)

	parameter	ADF ^a	p^b
constant	5.6853**		
trend	-0.0018**		
break. const.	-0.1682**		
break. trend	0.0012**		
PERRON		-2.83	12
AIC		-2.83	12
SCHWERT		-2.81	15

** significant at 5% level

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

of quite substantial extent, we cannot find an equilibrium path beside it. Before 1984 the risk measure is particularly biased because of deviating behavior in the beginning of the 1970s as well as because of some outliers between 1978 and 1982.

structural breaks (see chapter 5.1.4). Thus, the parameters of the fitted series might be biased.

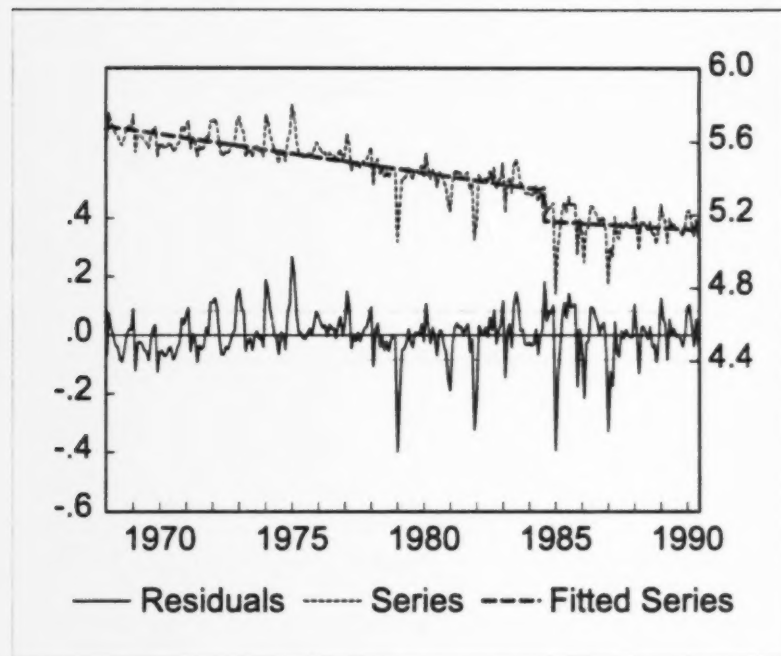


Figure 6.1: Ratio between accidents with bodily damages and all types of accidents (seasonal adjusted, natural logs), structural break in August, 1984, West German series

Non-stationarity is not completely reducible to the considered break in August, 1984. Thus, any quantitative interpretation is of a speculative nature. We do not find a stable equilibrium path prior to August, 1984. This path would have to serve as the reference point for potential deviations after the modeled break. Because it is missing we terminate our investigation regarding this risk measure. We do not estimate deviations applying dummy variables.

Finally, we cannot give a completely satisfying answer to hypothesis 1.4. Non-stationarity in the ratio between accidents with bodily damages and all types of accidents cannot be rejected even if we model a structural break in August, 1984. The graphical representation as shown in figure 6.1 points to a non-rejection of the first part of the hypothesis. The proportion of accidents with bodily damages decreases after August, 1984. Thus, such accidents are completely prevented. Furthermore, the negative shift in the constant is accompanied by a positive shift

in the time trend. It appears that the positive safety effects level off in the long run. Hypothesis 1.4 is not rejected.

6.5 Accident Frequency

Accident frequency is based on fuel sales. These figures are available only from January, 1968, until December, 1989. Thus, we cannot perform an ADF test in a sample lasting until December, 1998. The ADF test with a structural break in August, 1984, for the sample from January, 1968, until December, 1989, does not reject non-stationarity as shown in table 6.11.

Table 6.11: ADF test (break in 08/1984), accident frequency, West German series (sample: 01/1968-12/1989)

	parameter	ADF ^a	p ^b
constant	4.4083**		
trend	-0.0010**		
break, const.	-0.1672**		
break, trend	0.0005		
PERRON		-2.41	7
AIC		-1.64	18
SCHWERT		-1.82	15

** significant at 5% level

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

In figure 6.2 it becomes clear that the accident frequency is affected more by other events than the intensified seat belt legislation. The series decreases substantially until the middle of the 1970s. In light of this decrease it appears to be almost unaffected after August, 1984.³ We do not find a stable equilibrium path prior to

³ With respect to the graph in figure 6.2 the same holds as already stated in footnote 2, p. 84.

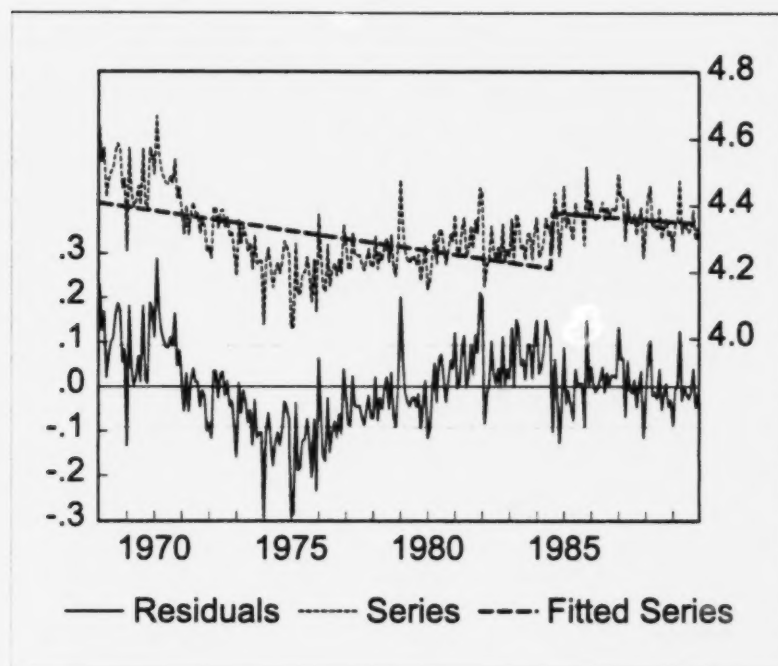


Figure 6.2: Accident frequency (seasonal adjusted, natural logs), structural break in August, 1984, West German series

August, 1984. Thus, we do not estimate quantitative effects (see the discussions in chapter 6.4 as well as in chapter 5.1.5.2).

The answer to hypothesis 1.5 is as unsatisfying as it was to hypothesis 1.4. Non-stationarity in accident frequency cannot be rejected, even if a break in August 1984 is modeled. This risk measure appears to be affected by other exogenous events than just the considered intensification of seat belt legislation. The graphical representation in figure 6.2 points to a non-rejection of hypothesis 1.5. Nevertheless, this is not supported by an unequivocal test result.

Table 6.12: Empirical results regarding the intensified seat belt legislation, West Germany

hypothesis	risk measure	result	result: break in		conclusion	hypothesis
		stationarity	constant	trend	safety effects	
1.1	fatalities per accident with bodily damages	trend-stationary, no break sample: 01/1968-06/1990	-	-	no effects	rejected
1.2	severely injured per accident with bodily damages	trend-stationary, break in 08/1984, sample: 01/1968-06/1990	negative	negative	positive, increasing	not rejected
1.3	lightly injured per accident with bodily damages	trend-stationary, break in 08/1984, sample: 01/1968-06/1990	-	positive	negative, increasing	not rejected
1.4	ratio between accidents with bodily damages and all accidents	non-stationary, sample: 01/1968-06/1990	-	-	rather positive, non-persistent ^a	not rejected ^a
1.5	accident frequency	non-stationary, sample: 01/1968-12/1989	-	-	rather no effects ^a	not rejected ^a

^a result is not based on an equilibrium path

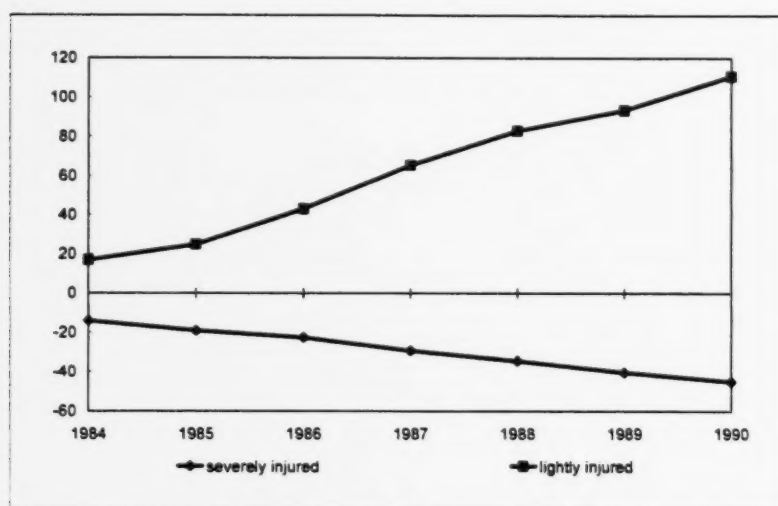


Figure 6.3: Absolute effects of the intensified seat belt legislation, changes in the number of injured persons per 1,000 accidents with bodily damages, West German series

6.6 Summary

The effects of the intensified seat belt legislation are summarized in table 6.12. Significant effects after August, 1984, are limited to the various degrees of injuries. The number of more severe injuries decreases, while the number of minor injuries increases (see figure 6.3). In the case of fatal accidents significant additional effects cannot be found. It appears that a substantial part of accidents with bodily damages is completely prevented (see figure 6.1). Accident frequency, in turn, remains unaffected after August 1984 (see figure 6.2).

Some of the ADF tests do not lead to highly significant results, e. g., regarding the number of lightly injured persons (table 6.7). Road traffic as well as traffic safety may be affected by numerous parameters, like prices, taxes, investments in road as well as in car infrastructure, traffic safety politics etc. Our results show that we can reduce relevant deviations from an underlying equilibrium path to one single event, the intensified seat belt legislation in Germany in August, 1984. The remaining estimation error is less than 10% regarding fatalities as well as

lightly injured, and severely injured accident victims.

Another finding is the complex lag structure in some estimations of absolute effects, e. g., regarding severely injured persons per accident with bodily damages (see table 6.5). Given our test methodology, the BREUSCH-GODFREY test (see chapter 5.2.2), the lag structure is as parsimonious as possible. The most economical lag structure is adopted starting with ARMA(1,0) followed by ARMA(0,1), ARMA(0,2), ARMA(1,1), ARMA(2,0), ARMA (2,1) and so on.

6.7 Concluding Remarks

General Results

We find some support for the notion that intensified seat belt legislation leads to a reduction of severe injuries. This is consistent with the findings in literature as already stated in chapter 4.1.2. Because of the structure of the investigated risk measures (victims per accident with bodily damages, see chapter 4.3) the rise in the number of lightly injured persons after the introduction of the new seat belt law (see figure 6.3) is not necessarily interpretable as a confirmation of the findings by GRIME (1979) or CAMERON (1981). They found increases in minor injuries due to seat belt wearing. As already discussed in chapter 4.4.1 it is very unlikely that all of the measures decrease or increase simultaneously after the event in question. A better indicator to evaluate minor injuries would be the prevention or non-prevention of an injury. As shown in figure 6.1 the proportion of accidents with bodily damages decreases.⁴ This result is, however, not based on a stationary model.

In light of these findings, the increase in the number of lightly injured persons appears to be as a result of prevented severe injuries. The increase of the number of lightly injured persons is more substantial than the decrease of the number

⁴ Also COOPER (1994) found some support that seat belt diminishes light injuries (see chapter 4.1.2).

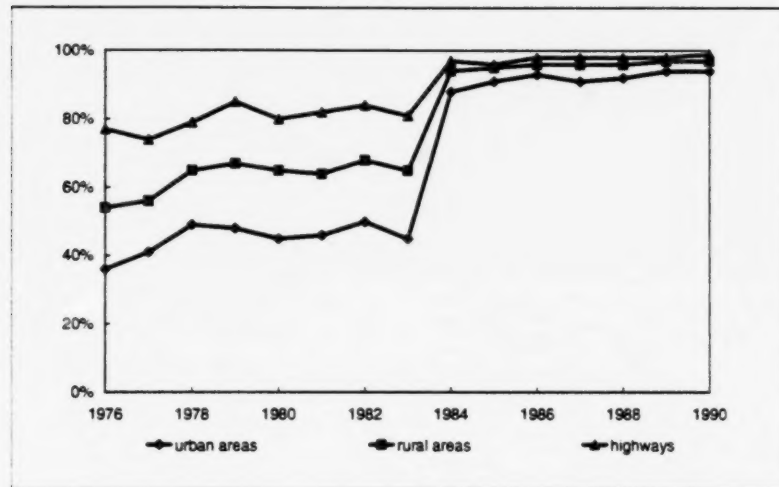


Figure 6.4: Belt usage rates in West Germany on different road types, sources: DIW (1988, p. 135) and DIW (1993, p. 150)

of severely injured persons. Hence, both explanations concerning minor injuries may be true. On the one hand, some minor injuries are completely prevented (decreasing proportion of accidents with bodily damages), while on the other hand, some specific minor injuries may be caused by seat belt wearing (see, e. g., the examples given by GRIME, 1979).

The effects of the intensified seat belt legislation are insignificant with respect to fatalities per accident with bodily damages. No break is observable in this risk measure. We may conclude that drivers fasten the belt when they are in a comparably dangerous situation even if no penalty exists.⁵ This finding is supported by the already high belt usage rates on highways prior to the new seat belt law (see figure 6.4). The shift in the belt usage rate on highways (from 81% in March 1984 to 97% in September 1984, DIW, 1993, p. 150) is less than that on all other road categories (e. g., from 47% in March 1984 to 88% in September 1984 in urban areas, DIW, 1993, p. 150).

⁵ Such a situation is, for example, a trip on the highway, where the average speed is high. The probability of fatal consequences is higher than on all other road types.

Risk Homeostasis

Two types of risk homeostasis generally exist (see chapter 3.1.2): long-term risk adjustment and risk substitution. In light of our results risk adjustment cannot be confirmed. We observe a substantial decrease in accident severity, while accident frequency remains almost constant due to intensified seat belt legislation (see table 6.12). Long-term risk adjustment is also not confirmed. All of the observed effects are persistent, and some even increase. The last result will be discussed below in more detail. In the limited domain of road traffic we have to reject risk homeostasis due to intensified seat belt legislation. This measure leads to significant positive safety effects in preventing severe accident consequences.

We find neither significant positive nor significant negative safety effects concerning fatalities per accident with bodily damages after the seat belt legislation. This appears to be consistent with the findings in literature referring to fatalities and the uselessness of non-motivational safety measures (see, e. g., WILDE, 1982b; WILDE and KUNKEL, 1984).⁶ Nevertheless, this result does not inevitably contradict other results which attribute substantial positive safety effects to seat belt wearing (see chapter 4.1.2). Usage rates in Germany were already quite high, in particular on highways (see figure 6.4). Thus, significant additional effects of the event under consideration concerning the fatalities are less probable. Furthermore, and in compliance with many other investigations (again, see chapter 4.1.2), positive effects (preventing severe injuries) are found with respect to the injured accident victims.

Increasing Long-Term Effects

Another noteworthy finding is the increasing safety effect in the long run as shown in figure 6.3. The hypotheses 1.2 and 1.3 are not refuted by the empirical results.

⁶ WILDE (1982b) as well as WILDE and KUNKEL (1984) do not explicitly refer to fatalities per accident with bodily damages. They apply other risk measures like the frequency of accidents with fatal consequences.

Changing time trends such that the safety effects in the long-run even increase were not expected.

After the intensification of the seat belt legislation more and more severe injuries were prevented at the cost of disproportional more light injuries. This might be attributed to some additional safety measures at that time, e. g., the introduction of airbag systems in new cars. These safety devices were not mandated by law but came into effect step by step. Thus, additional breaks in the time series were not observable. All these measures may have forced the positive trend in preventing severe injuries in traffic accidents even if this is accompanied by an increase in minor injuries.

Chapter 7

Empirical Results: German Reunification

In this chapter we present the results of the empirical analysis of German reunification. The investigation is divided into two parts. First, we present the results of the analysis of the West German series based on the theoretical hypotheses stated in chapter 4.4.2.1 and the operational hypotheses stated in chapter 5.4.2. Second, the same is done regarding the German series based on the hypotheses stated in chapters 4.4.2.2 and 5.4.2.¹ Finally, we summarize these results and draw some conclusions.

7.1 West Germany

Since we cannot analyze more than one break at a time (see chapter 5.1.3), we analyze the West German series starting in August, 1984, and lasting until December, 1998 (see chapter 4.3).² The analyzed sub-sample contains a break in

¹ When we speak about the German series we mean West German figures until December, 1990, and West plus East German figures from January, 1991, until December, 1998.

² One exception exists: we did not find a break in fatalities per accident with bodily damages

July, 1990, the time when the German Mark was introduced as the official currency in East Germany (see chapter 5.3). Non-stationarity without a structural break was not rejected in any considered series in the sample from January, 1968, to December, 1998. We, therefore, immediately apply stationarity tests with a structural break in July, 1990.

7.1.1 Fatalities per Accident with Bodily Damages

Table 7.1: ADF test (break in 07/1990), fatalities per accident with bodily damages, West German series (sample: 01/1968-12/1998)

	parameter	ADF ^a	<i>p</i> ^b
constant	4.0275**		
trend	-0.0034**		
break. const.	0.0595**		
break. trend	0.0010**		
PERRON		-3.70*	15
AIC		-3.89*	14
SCHWERT		-3.71*	16

* ** significant at 10/5% level

^a *t* statistic of estimated parameter β_{k-1} in ADF test

^b number of included lags in ADF test

The results of the ADF test for stationarity with a structural break in June, 1990, are shown in table 7.1. Since we did not find a structural break due to intensified seat belt legislation in August, 1984 (see chapter 6.1), we apply the test for the whole sample from January, 1968, to December, 1998. We observe a significant change in the constant as well as in the time trend. The risk measure follows an equilibrium path until July, 1990, and moves to another one after this date.

in August, 1984. For this series we will investigate the sample from January, 1968, until December, 1998.

Table 7.2: Deviations from the equilibrium path (1990-1998), fatalities per 1,000 accidents with bodily damages, West German series (sample: 01/1968-12/1998)

	parameter	t statistic
constant	60.64	(54.15)
trend	-0.14	(-18.18)
1990	2.19	(1.84)
1991	4.46	(3.00)
1992	5.24	(3.16)
1993	6.53	(3.70)
1994	7.43	(4.04)
1995	8.64	(4.54)
1996	9.68	(4.92)
1997	10.59	(5.22)
1998	10.56	(5.05)
ARMA(p,q)	1.9	

The series is trend-stationary with this structural break. A slightly negative time trend is observable prior to the break. The break in the time trend has a positive sign, but it does not exceed the former overall time trend in absolute values. Thus, the trend remains decreasing after the break, but it is less steep. We additionally find a significant positive shift in the constant. An adjustment to the former path cannot be observed.

The quantitative effects in absolute numbers are shown in table 7.2. The above-stated results are confirmed in the analysis. The effects that were suddenly occurring become even more substantial in the long run; then, however, their effect is less visible in absolute numbers. Finally, the results regarding the fatalities per accident with bodily damages can be summarized as follows. After the German reunification we observe a significant sudden increase in this risk measure in the West German series, and the effects even increase in the long run. Hypothesis 2.1 is not rejected. The effects are to a lesser extent in absolute numbers.

7.1.2 Severely Injured Persons per Accident with Bodily Damages

In table 7.3 the results of the ADF test for stationarity with a structural break are shown. Since we already found a break due to intensified seat belt legislation in this series in August, 1984 (see chapter 6.2), we only consider the sub-sample from August, 1984, to December, 1998. Even though a significant break in the time trend is observable in July, 1990, non-stationarity is not rejected despite this modeled break. The sub-sample from January, 1968, to June, 1990 is trend-stationary with structural break (see table 6.4). There exists an equilibrium path prior to July, 1990. German reunification may, therefore, affect this measure, but the deviations from the equilibrium path cannot solely be attributed to this single event. Other unconsidered events beside the seat belt legislation and German reunification after July, 1990, also cause breaks in the series.

Based on the equilibrium path prior to July, 1990, we can estimate the deviations from this path after the modeled break. The results are summarized in table 7.4. Because of the break found in August, 1984, we include two dummy variables

Table 7.3: ADF test (break in 07/1990), number of severely injured persons per accident with bodily damages, West German series, (sample: 08/1984-12/1998)

	parameter	ADF ^a	<i>p</i> ^b
constant	5.8909**		
trend	-0.0024**		
break, const.	0.0026		
break, trend	0.0012**		
PERRON		-3.25	15
AIC		-2.87	14
SCHWERT		-2.70	13

** significant at 5% level

^a *t* statistic of estimated parameter ρ_{t-1} in ADF test

^b number of included lags in ADF test

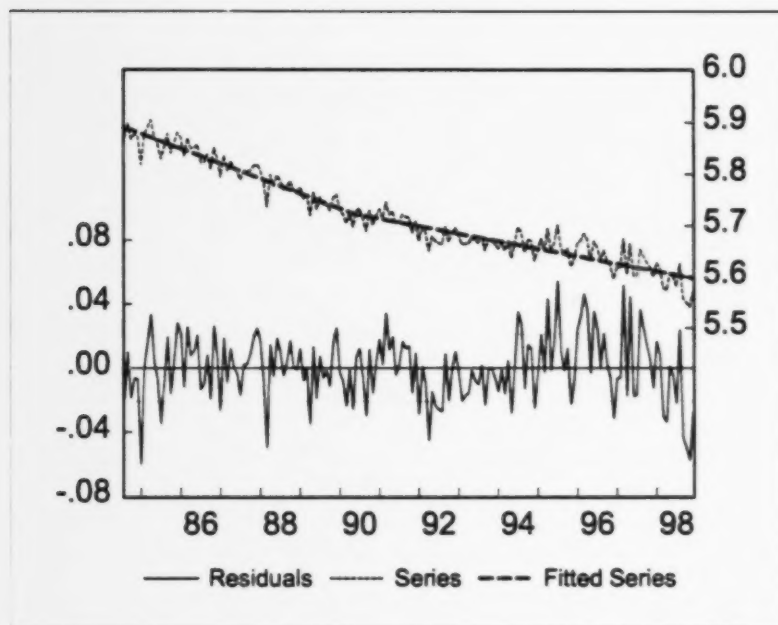


Figure 7.1: Number of severely injured persons per accident with bodily damages (seasonal adjusted, natural logs), structural break in July, 1990, West German series

D_C and D_T covering this first break in the series. This procedure allows us to estimate the deviations with respect to the second break in July, 1990 (see also chapter 5.2.3). As can be seen, the effects are insignificant right after the reunification. This confirms the finding of the ADF test in which no significant break in the constant was found. In 1994 the effects become significant and they do not level off in the long run. Hypothesis 2.2 has to be partly rejected. Note again that German reunification is not the only event affecting this risk measure in the 1990s.

Table 7.4: Deviations from the equilibrium path (1990-1998), number of severely injured persons per 1,000 accident with bodily damages, West German series (sample: 01/1968-12/1998)

	parameter	<i>t</i> statistic
constant	447.91	(156.63)
trend	-0.35	(-17.51)
dummy in constant, D_C (08/1984)	-14.33	(-3.58)
dummy in time trend, D_T (08/1984)	-0.44	(-4.70)
1990	-1.24	(-0.25)
1991	8.70	(1.39)
1992	6.65	(0.92)
1993	13.74	(1.70)
1994	21.49	(2.38)
1995	29.76	(2.98)
1996	36.65	(3.34)
1997	40.15	(3.35)
1998	38.52	(2.96)
ARMA(p,q)	5.2	

$D_C = 1$ if $t \geq t_{08/84}$, zero otherwise

$D_T = t - t_{08/84}$ if $t \geq t_{08/84}$, zero otherwise

7.1.3 Lightly Injured Persons per Accident with Bodily Damages

Table 7.5 shows the results of the ADF test for stationarity with structural break. After applying SCHWERT's methodology (SCHWERT, 1987, see also chapter 5.1.4), the test did not reject non-stationarity, while the other two procedures reject non-stationarity. In those two procedures the lag structure p is much more complex than in SCHWERT's procedure. Since a more complex lag structure should lead to a non-rejection of non-stationarity (GERDTHAM and LÖTHGREN, 1999), we

Table 7.5: ADF test (break in 07/1990), number of lightly injured persons per accident with bodily damages, West German Series (sample: 08/1984-12/1998)

	parameter	ADF ^a	<i>p</i> ^b
constant	6.8317**		
trend	0.0013**		
break, const.	-0.0067*		
break, trend	-0.0008**		
PERRON		-4.75**	20
AIC		-4.42**	19
SCHWERT		-3.32	13

*/** significant at 10/5% level

^a *t* statistic of estimated parameter β_1-1 in ADF test

^b number of included lags in ADF test

can adopt stationarity with a structural break in July, 1990. The break in the constant is negative, but it is not very significant. It is also of a lesser extent compared to the starting level in August, 1984. Since the break in the time trend is also negative, the former increasing trend becomes less steep.

The estimated deviations from the equilibrium path are summarized in table 7.6. Again, we modeled a break in August, 1984, by the two dummy variables D_C and D_T . These numbers confirm the results already stated above in the ADF test. The effects are insignificant at the beginning of the 1990s and, thus, sudden changes do not occur. The effects become significant in 1992. They even increase until 1998. In light of the found equilibrium path after July, 1990, we can attribute the estimated deviations to the modeled single break at this date. Because of the missing sudden effects as well as the non-observable offset of the deviations in the long run, hypothesis 2.3 is partly rejected.

Table 7.6: Deviations from the equilibrium path (1990-1998), number of lightly injured persons per 1,000 accident with bodily damages, West German series (sample: 01/1968-12/1998)

	parameter	t statistic
constant	958.75	(183.90)
trend	-0.23	(-7.78)
dummy in constant, D_C (08/1984)	6.93	(1.04)
dummy in time trend, D_T (08/1984)	1.48	(9.45)
1990	-0.48	(-0.05)
1991	-19.68	(-1.82)
1992	-26.45	(-2.16)
1993	-32.75	(-2.39)
1994	-41.20	(-2.70)
1995	-49.28	(-2.92)
1996	-58.87	(-3.17)
1997	-75.99	(-3.75)
1998	-75.77	(-3.45)
ARMA(p,q)	3.2	

$D_C = 1$ if $t \geq t_{08/84}$, zero otherwise

$D_T = t - t_{08/84}$ if $t \geq t_{08/84}$, zero otherwise

7.1.4 Ratio Between Accidents with Bodily Damages and All Types of Accidents

The results of the ADF test with a structural break are shown in table 7.7. Non-stationarity cannot be rejected; neither prior to July, 1990, nor after this date did the series follow an equilibrium path. In particular, there exists no fundamental equilibrium path prior to the modeled break and, thus, we do not estimate quantitative effects (see the discussions in chapter 6.4 as well as in chapter 5.1.5.2).

Table 7.7: ADF test (break in 07/1990), ratio between accident with bodily damages and all types of accidents, West German series (sample: 08/1984-12/1998)

	parameter	ADF ^a	p ^b
constant	5.1685**		
trend	-0.0007		
break, const.	-0.0135		
break, trend	0.0015**		
PERRON		-3.75	20
AIC		-3.40	19
SCHWERT		-3.25	13

** significant at 5% level

^a t statistic of estimated parameter γ_{t-1} in ADF test

^b number of included lags in ADF test

As is visible in the graph of the risk measure (see figure 7.2), German reunification appears to be of minor relevance to the changes in the proportion of accidents with bodily damages.³ Some other events affect this risk measure more substantially during the mid 1990s. Those events are, however, not considered in our investigation. German reunification only marginally affects the ratio between accidents

³ The fitted series is based on non-adjusted residuals in the OLS estimation (see also footnote 2, p. 84).

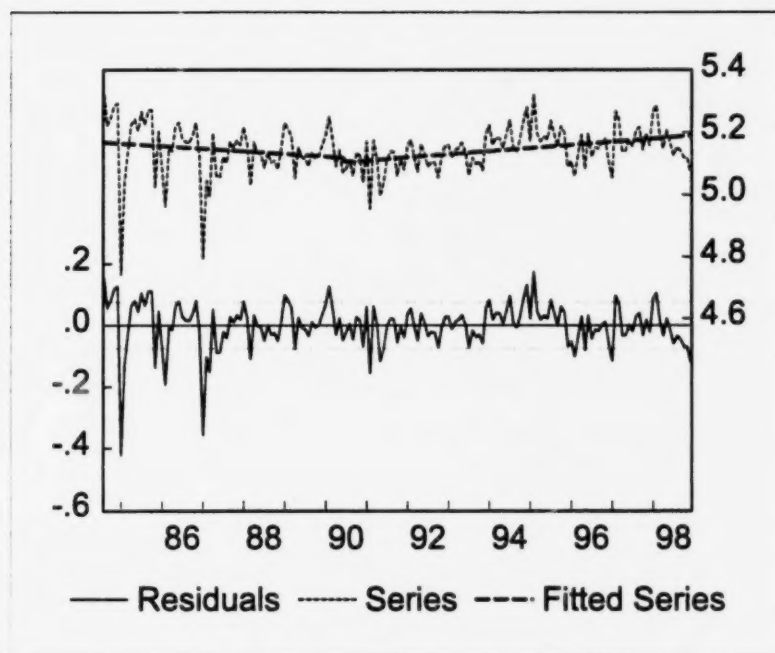


Figure 7.2: Ratio between accidents with bodily damages and all types of accidents (seasonal adjusted, natural logs), structural break in July, 1990, West German series

with bodily damages and all types of accidents in West Germany. As shown in table 7.7 the proportion of this accident type increases in the long run (break in the time trend). Because of the missing significant break in the constant, sudden changes cannot be observed. Even if these results are not based on a rejected non-stationarity hypothesis they point to a partial rejection of hypothesis 2.4.

7.1.5 Summary

The effects of German reunification in West Germany are summarized in table 7.8. Sudden changes of a substantial extent are not observed (see figure 7.3). Only the former time trends change. Severe injuries and fatalities occur more frequently per 1,000 accidents with bodily damages. Thus, we observe a slight increase in accident severity. The decrease in the number of lightly injured persons, in turn,

Table 7.8: Empirical results regarding German reunification, West Germany

hypothesis	risk measure	result		result: break in		conclusion		hypothesis
		stationarity	trend	constant	trend	safety effects		
2.1	fatalities per accident with bodily damages	trend-stationary, break in 07/1990, sample: 01/1968-12/1998		marginally positive	positive	marginally negative, increasing		not rejected
2.2	severely injured per accident with bodily damages	non-stationary, sample: 08/1984-12/1998				marginally negative, marginally increasing ^a		partly rejected ^a
2.3	lightly injured per accident with bodily damages	trend-stationary, break in 07/1990, sample: 08/1984-12/1998		marginally negative	negative	marginally positive, marginally increasing		partly rejected
2.4	ratio between accidents with bodily damages and all accidents	non-stationary, sample: 08/1984-12/1998				rather negative, marginally increasing ^a		partly rejected ^a

^a result is not based on an equilibrium path

is disproportionately high. The absolute number of victims (fatalities, severely, and lightly injured persons) per 1,000 accidents with bodily damages slightly decreases.⁴

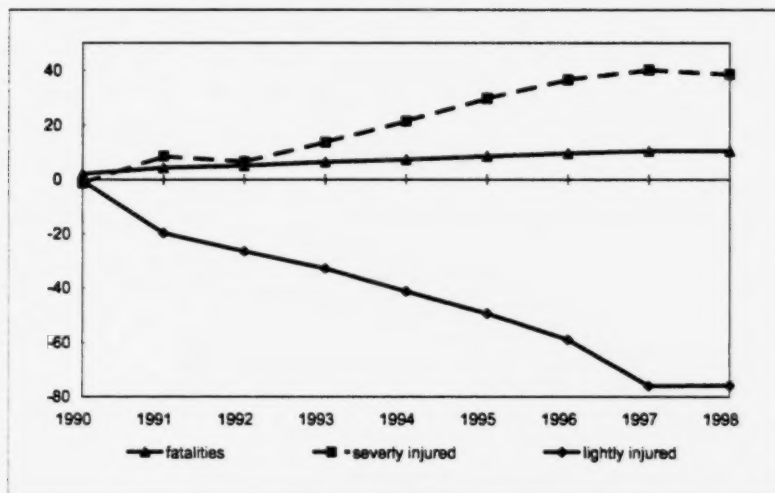


Figure 7.3: Absolute effects of German reunification, changes in the number of victims per 1,000 accidents with bodily damages, West German series

Nevertheless, we do not find an equilibrium path in the number of severely injured persons after July, 1990 (denoted by the dashed line in figure 7.3). In the ratio between accidents with bodily damages and all types of accidents before and after the event in question an equilibrium path cannot be found, too. German reunification is, therefore, not the sole event substantially affecting traffic accident risks in West Germany: other unconsidered events lead to the found changes in these risks.

⁴ This result has to be interpreted as a negative trend in traffic safety. However, the number of lightly injured persons decreases. We, therefore, denote this shift as a positive one in table 7.16.

7.2 Unified Germany

Under the focus of the unified German we investigate series containing West German figures until December, 1990, and German figures from January, 1991, until December, 1998 (see chapters 4.3 and 5.3). Because of this explicit break in the database we adopt January, 1991, as the date of the break regarding the German reunification. We neglect the break in July, 1990, as already investigated in chapter 7.1. This is necessary because of the methodology applied (see chapter 5.1.3). We only find marginal effects in the West German series after German reunification (see chapter 7.1.5). This limitation is, therefore, not too restrictive.

We already investigated a break due to the intensified seat belt legislation in West German series. Thus, below we only consider the sub-sample from August, 1984, to December, 1998. Again, one exception exists in the analysis, the fatalities per accident with bodily damages (see footnote 2, p. 96).

7.2.1 Fatalities per Accident with Bodily Damages

The results of the ADF test for stationarity with a structural break are shown in table 7.9. As shown above (see chapter 6.1) we did not find a break due to the intensified seat belt legislation. Because of this missing break we apply the test for the whole sample from January, 1968, to December, 1998. Trend-stationarity with a structural break is adopted. We can conclude that German reunification is the only event significantly changing the equilibrium path of this risk measure. We observe a break in the constant, while the break in the time trend is statistically insignificant. The number of fatalities per 1,000 accidents with bodily damages suddenly increases in January, 1991, while the overall time trend does not change.

Table 7.9: ADF test (break in 01/1991), fatalities per accident with bodily damages, series of the unified Germany (sample: 01/1968-12/1998)

	parameter	ADF ^a	<i>p</i> ^b
constant	4.0262**		
trend	-0.0033**		
break, const.	0.2797**		
break, trend	-0.0004		
PERRON		-3.84*	15
AIC		-3.94*	19
SCHWERT		-3.89*	16

*/** significant at 10/5% level

^a *t* statistic of estimated parameter ν_{t-1} in ADF test

^b number of included lags in ADF test

Table 7.10: Deviations from the equilibrium path (1991-1998), fatalities per 1,000 accidents with bodily damages, series of the unified Germany (sample: 01/1968-12/1998)

	parameter	<i>t</i> statistic
constant	58.55	(43.70)
trend	-0.12	(-17.05)
1991	9.04	(6.89)
1992	8.65	(5.14)
1993	9.27	(5.01)
1994	9.93	(5.11)
1995	10.91	(5.42)
1996	11.41	(5.51)
1997	11.94	(5.60)
1998	11.61	(5.29)
ARMA(p,q)	1,9	

The absolute deviations from the expected equilibrium path in West Germany under the assumption that the reunification has not taken place are shown in table 7.10. These quantitative effects are quite substantial right after the break. During the 1990s they are almost stable. Thus, the findings stated above are confirmed by the ADF test. We do not find an offset of these effects in the long run. Because of these empirical results hypotheses 3.1 is partly rejected.

7.2.2 Severely Injured Persons per Accident with Bodily Damages

Table 7.11 shows the results of the ADF test for stationarity with a structural break. For the number of the severely injured persons per accident with bodily damages the same holds as already stated for West Germany (see chapter 7.1.2): we cannot find a stable equilibrium path after January, 1991. Other events besides German reunification affect this risk measure. However, the reunification lead to a

Table 7.11: ADF test (break in 01/1991), number of severely injured persons per accident with bodily damages, series of the unified Germany (sample: 08/1984-12/1998)

	parameter	ADF ^a	p ^b
constant	5.8888**		
trend	-0.0024**		
break, const.	0.1353**		
break, trend	0.0007**		
PERRON		-2.19	15
AIC		-1.96	19
SCHWERT		-1.68	13

** significant at 5% level

^a t statistic of estimated parameter y_{t-1} in ADF test

^b number of included lags in ADF test

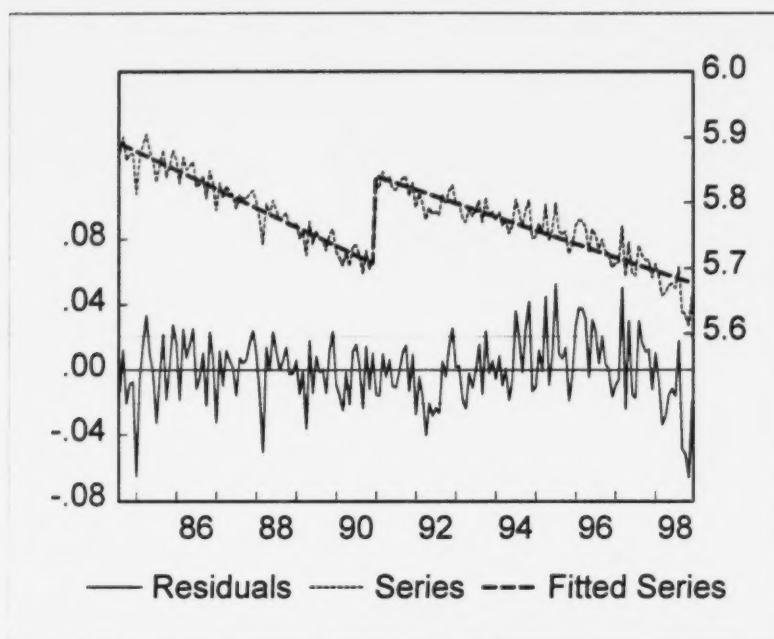


Figure 7.4: Severely injured persons per accident with bodily damages (seasonal adjusted, natural logs), structural break in January, 1991, German series

significant shift in the series (see figure 7.4).⁵ Thus, German figures substantially exceed the expected West German figures.

⁵ The fitted series as shown in figure 7.4 is not based on adjusted residuals (see also footnote 2, p. 84).

Table 7.12: Deviations from the equilibrium path (1991-1998), number of severely injured persons per 1,000 accident with bodily damages, series of the unified Germany (sample: 01/1968-12/1998)

	parameter	t statistic
constant	448.11	(159.25)
trend	-0.35	(-17.73)
break in constant, D_C (08/1984)	-14.19	(-3.73)
break in time trend, D_T (08/1984)	-0.45	(-5.87)
1991	44.87	(8.91)
1992	44.52	(7.39)
1993	50.84	(7.62)
1994	56.60	(7.69)
1995	60.49	(7.49)
1996	65.95	(7.47)
1997	65.99	(6.87)
1998	61.43	(5.91)
ARMA(p,q)	5.2	

$$D_C = 1 \text{ if } t \geq t_{08/84}, \text{ zero otherwise}$$

$$D_T = t - t_{08/84} \text{ if } t \geq t_{08/84}, \text{ zero otherwise}$$

We already found a stable equilibrium path prior to German reunification in this risk measure (see chapter 6.2). Because of this path we can compute deviations after January, 1991, as shown in table 7.12. An equilibrium path after January, 1991, is missing. The found deviations must, therefore, be partly attributed to events other than German reunification. As shown in figure 7.4, the reunification appears to have the most significant effect. The effects further increase in the long run. Because of the break in the constant as well as the non-observable offset of the effects in the long run, hypothesis 3.2 is not rejected.

7.2.3 Lightly Injured Persons per Accident with Bodily Damages

The results of the ADF test for stationarity with a structural break are shown in table 7.13. Non-stationarity is rejected. We, therefore, adopt a trend-stationary model with a structural break in January, 1991. A significant break occurs in the constant as well as in the time trend. The formerly increasing time trend becomes less steep and moves to a lower level after January, 1991.

Table 7.13: ADF test (break in 01/1991), number of lightly injured persons per accident with bodily damages, series of the unified Germany (sample: 08/1984-12/1998)

	parameter	ADF ^a	p ^b
constant	6.8318**		
trend	0.0013**		
break, const.	-0.0555**		
break, trend	-0.0006**		
PERRON		-4.25**	20
AIC		-4.39**	19
SCHWERT		-4.87***	13

/ significant at 5/1% level

^a t statistic of estimated parameter ρ_{t-1} in ADF test

^b number of included lags in ADF test

The deviations of the figures of reunified Germany from the expected equilibrium path of the West German figures without reunification are shown in table 7.14. The above-stated results are confirmed. We find a small downward shift in the number of lightly injured persons per accident with bodily damages. The deviations from the expected equilibrium path increase in the long run. In the reunified Germany the number of lightly injured persons per 1,000 accidents with bodily damages is increasing less than the expected number in West Germany. Hypothesis 3.3 is not rejected.

Table 7.14: Deviations from the equilibrium path (1991-1998), number of lightly injured persons per 1,000 accident with bodily damages, series of the unified Germany (sample: 01/1968-12/1998)

	parameter	<i>t</i> statistic
constant	959.67	(182.99)
trend	-0.22	(-7.78)
dummy in constant, D_C (08/1984)	6.46	(1.04)
dummy in time trend, D_T (08/1984)	1.49	(12.05)
1991	-57.45	(-6.40)
1992	-67.18	(-6.73)
1993	-74.15	(-6.73)
1994	-82.63	(-6.81)
1995	-86.38	(-6.49)
1996	-94.85	(-6.53)
1997	-106.63	(-6.76)
1998	-105.65	(-6.19)
ARMA(p,q)	3.2	

$D_C = 1$ if $t \geq t_{08/84}$, zero otherwise

$D_T = t - t_{08/84}$ if $t \geq t_{08/84}$, zero otherwise

7.2.4 Ratio Between Accidents with Bodily Damages and All Types of Accidents

We do not find a stable equilibrium path with a structural break in the the ratio between accidents with bodily damages and all types of accidents (see table 7.15). As shown in figure 7.5 the proportion of accidents with bodily damages remains almost unaffected after January, 1991.⁶ This is supported by the statistically insignificant break in constant found in table 7.15. Other unconsidered events further affect this risk measure. In particular, we do not find a stable equilibrium path prior to January, 1991, and, thus, we do not estimate quantitative effects (see the discussions in chapter 6.4 as well as in chapter 5.1.5.2).

Table 7.15: ADF test (break in 01/1991), ratio between accidents with bodily damages and all types of accidents, series of the unified Germany (sample: 08/1984-12/1998)

	parameter	ADF ^a	<i>p</i> ^b
constant	5.1716**		
trend	-0.0008**		
break, const.	-0.0011		
break, trend	0.0009**		
PERRON		-3.28	14
AIC		-2.89	13
SCHWERT		-2.89	13

** significant at 5% level

^a *t* statistic of estimated parameter γ_{t-1} in ADF test

^b number of included lags in ADF test

This result can be summarized as follows. In the unified Germany the proportion of accidents with bodily damages deviates more and more from the expected figures in West Germany. Sudden effects are, however, not observable. This

⁶ The fitted series as shown in figure 7.5 is not based on adjusted residuals (see also footnote 2, p. 84).

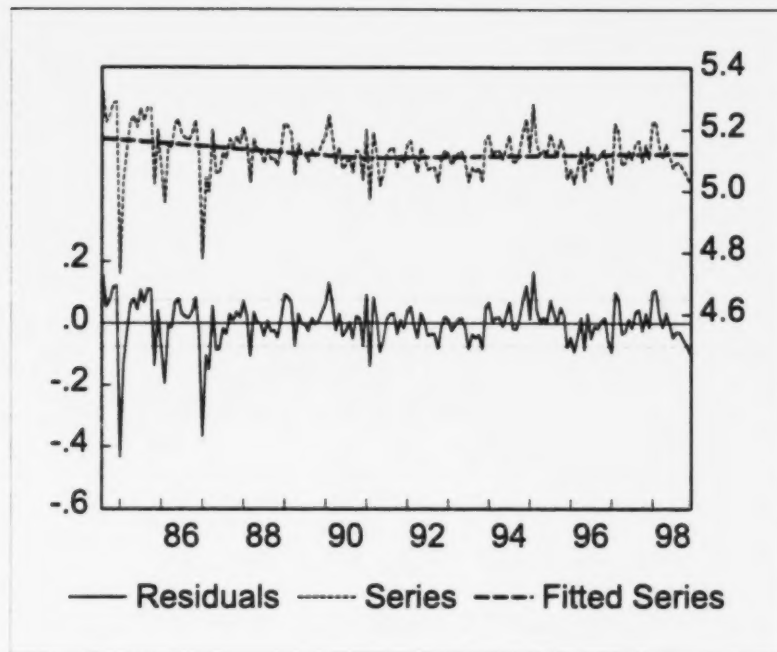


Figure 7.5: Ratio between accidents with bodily damages and all types of accidents (seasonal adjusted, natural logs), structural break in January, 1991, West German series

proportion is the same in West Germany as well as in the reunified Germany right after reunification. Hypothesis 3.4 is partly rejected. Nevertheless, this result is not based on a trend-stationary model with a structural break.

7.2.5 Summary

The effects of the reunification in the whole of Germany are summarized in table 7.16 and in figure 7.6. It becomes clear that the accident severity in terms of bodily damages in Germany substantially exceeds the expected severity in West Germany. The deviations of the number of severely injured persons are not based on an equilibrium path after the reunification (denoted by the dashed line in figure 7.6). In 1991 the shift in the number of lightly injured persons per 1,000 accidents with bodily damages almost equals the sum of the shifts of (a) the number of

Table 7.16: Empirical results regarding German reunification, unified Germany

hypothesis	risk measure	result	result: break in			conclusion	hypothesis
		stationarity	constant	trend		safety effects	
3.1	fatalities per accident with bodily damages	trend-stationary, break in 01/1991, sample: 01/1968-12/1998	positive			negative, persistent	partly rejected
3.2	severely injured per accident with bodily damages	non-stationary, sample: 08/1984-12/1998				negative, marginally increasing ^a	not rejected ^a
3.3	lightly injured per accident with bodily damages	trend-stationary, break in 01/1991, sample: 08/1984-12/1998	marginally negative	negative		positive, marginally increasing	not rejected
3.4	ratio between accidents with bodily damages and all accidents	non-stationary, sample: 08/1984-12/1998				rather negative, marginally increasing ^a	partly rejected ^a

^a result is not based on an equilibrium path

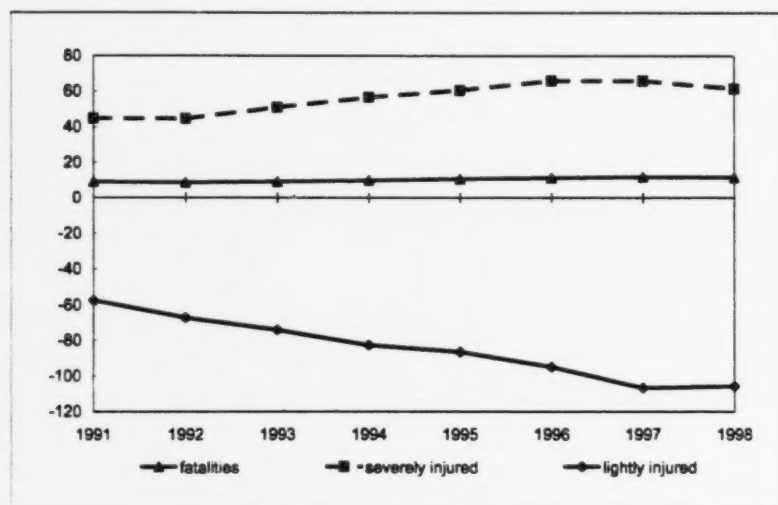


Figure 7.6: Absolute effects of German reunification, changes in the number of victims per 1,000 accidents with bodily damages, German series

severely injured persons and (b) the number of fatalities. The average severity of an accident with bodily damages in Germany substantially exceeds the expected severity in West Germany.⁷ The proportion of accidents with bodily damages in Germany approximately equals that in West Germany as shown in figure 7.5 (see also hypothesis 3.4 in table 7.16).

In the long run the number of fatalities per accident with bodily damages does not adjust to the expected figures in West Germany. It remains on a stable but a higher level. The number of severely injured persons slightly increases, while the number of lightly injured persons disproportionately decreases. The result concerning the number of severely injured persons is, however, based on a non-stationary process after January, 1991. We, therefore, conclude that it may be biased by other events during the 1990s which are not under consideration.

Because of the low significance level of the ADF test concerning the fatalities per

⁷ The shift in the number of lightly injured persons is denoted as a positive one. For this reason see footnote 4, p. 106.

accident with bodily damages (see table 7.9), the same interpretation holds as the one already mentioned in chapter 6.6. Furthermore, the estimations of the absolute effects lead to a complex structure of the ARMA(p,q) model (see tables 7.10 and 7.12). This problem was also discussed in chapter 6.6.

7.3 Concluding Remarks

Below we draw some conclusions from the described results of the empirical analysis of German reunification. We combine both investigated foci, West Germany as well as reunified Germany, and relate the findings to the risk homeostasis theory.

General Results

The additional effects of German reunification on the number of victims per 1,000 accident with bodily damages are summarized in figure 7.7. It becomes clear that the accident severity in reunified Germany is worse compared to West Germany. Since both foci contain West German data, the observed difference can be attributed to the comparably dangerous situation in East Germany. However, the general trend is the same: we observe a shift from minor injuries to more severe injuries and even fatalities in West Germany as well as in reunified Germany. Nevertheless, this shift is only marginal right after the considered break in July, 1990, in West Germany.

Divergent Break Points

As was already mentioned in chapter 5.3 the analysis is based on two different break points: (a) July 1, 1990, regarding West Germany and (b) January 1, 1991, regarding reunified Germany. This may bias the results. Some indicators lead us to expect that the empirical findings will be sufficiently robust:

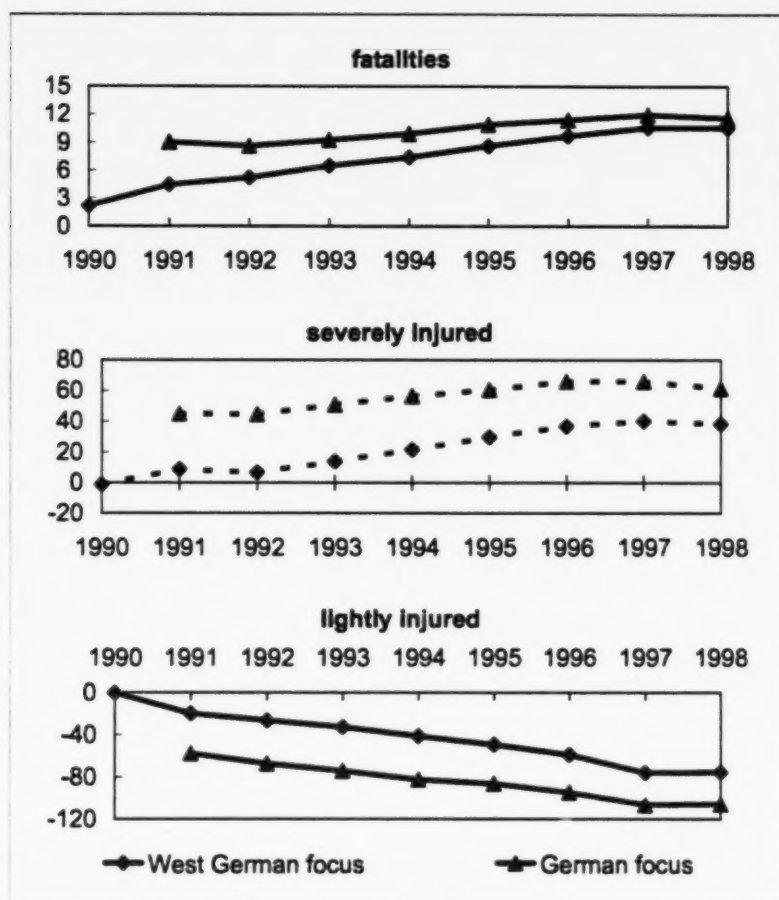


Figure 7.7: Deviations from the equilibrium path, victims per 1,000 accidents with bodily damages, West Germany and unified Germany

1. The effects of German reunification are marginal in West Germany. In particular, sudden effects (breaks in the constant) are either neglected or are of only a marginal extent (see table 7.8). The effects in the problematic period from July, 1990, to December, 1990, are less substantial. They are substantially exceeded by the effects in the reunified Germany (see, e. g., figure 7.7).
2. The results of the ADF test in reunified Germany (see table 7.13) are highly

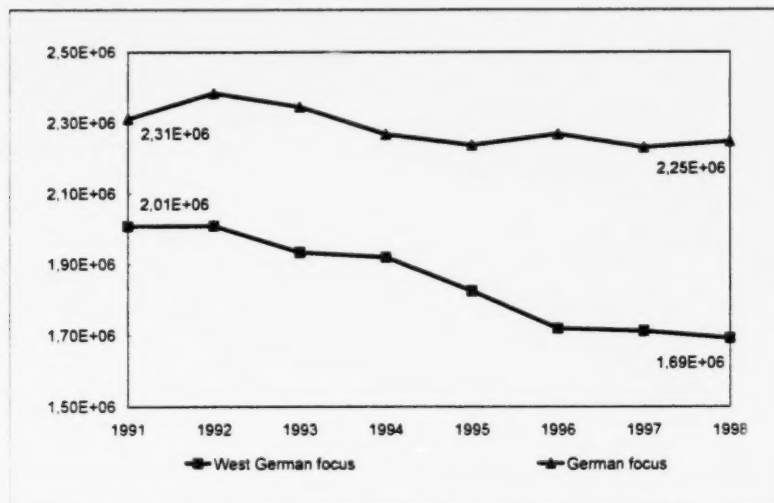


Figure 7.8: Number of accidents with bodily damages and with material damages, source: DIW (1999, pp. 159)

significant. Stationarity with a structural break in January, 1991, can be adopted.

Risk Homeostasis

We do not find evidence supporting a long-term risk adjustment in the equilibrium path in West Germany prior to German reunification. In fact, the effects on accident severity increase in the long run (see figure 7.7). Accident frequency, the other risk component, is not considered in detail because of the missing reliable database (see chapter 4.3). For that reason figure 7.8 shows the absolute number of accidents in West Germany between 1991 and 1998. Even if these figures do not take into consideration the traffic demand they allow the following interpretation. Since we observe a decrease in accident frequency of almost 16% between 1991 and 1998, risk substitution may occur. The negative trend in the accident severity after German reunification (see table 7.8) in West Germany appears to be accompanied by a decreasing accident frequency. In light of this finding risk homeostasis holds in the limited domain of road traffic in West Germany.

We cannot compare the trends in reunified Germany before and after the reunification which makes conclusions of homeostatic effects difficult.⁸ However, we find some weak evidence supporting risk substitution. The fatality rate per accident with bodily damages in reunified Germany substantially exceeds the expected West German level after the reunification (see figure 7.6). This deviation is almost stable in the long run. The actual fatality rate in West Germany deviates more and more from the expected rate after reunification (see figure 7.3). These findings support a disproportionally decreasing fatality rate in East Germany. The opposite holds regarding accident frequency (see figure 7.8). This figure decreases in West Germany, while it remains almost stable in reunified Germany. This allows us to conclude that the accident frequency increases in East Germany.

The two findings, (a) disproportional decreasing fatalities per accident with bodily damages in East Germany, and (b) increasing accident frequency in East Germany, weakly support the risk substitution hypothesis. Since figures prior to the reunification are not available for East Germany in the desired quality, this needs some further research.

⁸ Because of the missing database for reunified Germany prior to the reunification, the analysis of risk adjustment processes can only yield to some indicators. Furthermore, it might be unclear whether the adjustment of the series to the expected figures in West Germany are necessary to confirm the risk homeostasis thesis. Differences in accident frequency risk or in accident severity risk between reunified Germany and West Germany may come as the result of the different target risk of the East Germans compared to the West Germans.

Chapter 8

Theoretical Concepts Describing Human Behavior Under Uncertainty

Risk homeostasis theory is too general for an approach in analyzing individual decision-making processes under risk, in particular if we consider highly aggregated data, like the risk measures in the empirical analysis above (see also COLE and WITHEY, 1982; MCKENNA, 1985; 1988 and the review in chapter 2). In this chapter we will investigate three theoretical concepts of individual behavior under uncertainty and their implications to individual driving behavior. The introduced theoretical concepts serve as the basis in order to develop a model describing individual behavior in road traffic.

The next three sections describe human behavior in road traffic within the concepts of expected utility theory, prospect theory, and support theory. This presentation is accompanied by a sample which may clarify the theoretical concepts. For all of those who are familiar with these concepts this introduction is of less interest and can be skipped. Finally, the concepts are summarized and contrasted with respect to risk homeostasis theory.

8.1 Expected Utility Theory

Expected utility theory was formulated by VON NEUMANN and MORGENTERN (1944). This rational theory of choice describes human behavior assuming the availability of alternatives, particularly their outcomes and probabilities. The theory is further based on four basic axioms. These elements are introduced and discussed below.

In expected utility theory individual decision processes are based on a set of risky alternatives. Each alternative results in one of a number of possible outcomes. A **lottery** can be described by a set of outcomes $(x_1, \dots, x_n)$ and a set of probability values $(p_1, \dots, p_n)$. These can be interpreted as the probability p_n of outcome x_n occurring. Each lottery is evaluated by its **expected utility** u . It is defined as

$$u(x_1, p_1; \dots; x_n, p_n) = \sum_{i=1}^n p_i u(x_i) \quad (8.1)$$

The utility of each outcome is weighted by its probability of occurrence. The theory is based on four basic axioms (see, e. g., VON NEUMANN and MORGENTERN, 1944; SAVAGE, 1954; WEBER and CAMERER, 1987; CAMERER, 1989). The following situation serves as an illustrating example:

A manager may have to decide whether he travels by plane (lottery A), by train (lottery B), or by car (lottery C) to attend a meeting in a town 500 kilometers away. Lottery A may consist of a sure loss for the ticket prize $(x_{A,tp}, 1)$, a highly unlikely loss if the plane crashes $(x_{A,cr}, p_{A,cr})$, and a highly probable gain for saved time $(x_{A,ti}, (1 - p_{A,cr}))$ if he arrives. The lotteries B and C are similarly given by $(x_{B,tp}, 1; x_{B,cr}, p_{B,cr}; x_{B,ti}, (1 - p_{B,cr}))$ and $(x_{C,tp}, 1; x_{C,cr}, p_{C,cr}; x_{C,ti}, (1 - p_{C,cr}))$.

1. **Integrity:** Individuals can compare two lotteries such that they can decide which of them they prefer ($\prec$) or whether they are indifferent between them ($\sim$).

Given the integrity axiom the manager is able to compare all of the travelling modes in pairs. For each pair he can decide if he prefers a specific mode or whether he is indifferent to them.

2. **Transitivity:** If lottery A is preferred to lottery B and B is preferred to C then A is preferred to C .

If the manager prefers the plane over the train ($A \succ B$) and the train over the car ($B \succ C$) then he also prefers the plane over the car ($A \succ C$).

3. **Continuity:** If $A \prec B \prec C$ then there exists a unique probability p such that $B \sim pA + (1 - p)C$.

The preferences of the manager may be given by $A \succ B \succ C$. There exists a combination of the two travelling modes plane and car that is as good as travelling by train. A combination of the two travelling modes means that one part of the journey is covered by plane, while the remaining part is covered by car. The manager's first opportunity is to travel from the office to the airport by car and using the plane afterwards. He can alternatively use the train for the whole journey, since the train station is next to his office. The longer the distance to the airport the less is the preference for the plane/car combination. The probability $1 - p$ as stated in axiom 3 can be interpreted as the distance from the office to the airport relative to the distance from the office to the location where the meeting takes place.

4. **Independence:** If $A \sim B$ then $pA + (1 - p)C \sim pB + (1 - p)C$.

Let us assume that the manager is indifferent between the plane and the train ($A \sim B$). Furthermore, the airport and the train station are at the same place. If he uses the car to travel from the office to the airport/train station then this indifference remains stable no matter where his office is situated relative to the airport/train station.

Surveys of expected utility theory and its advancements can be found in SLOVIC and TVERSKY (1974), MACHINA (1982), ARROW (1982), SUGDEN (1986), WEBER and CAMERER (1987), and CAMERER (1989).¹ Some of these findings are discussed in more detail below.

FRIEDMAN and SAVAGE (1948) referred to the diminishing marginal utility principle. It implies that a fair game can never be attractive for individuals. The utility of a 50% chance to win a dollar is less valued than the utility of a 50% chance to lose a dollar in absolute values. The authors suggested a utility function such that individuals are risk-averse in low income cases (low level of ultimate wealth, buy insurances). They are risk takers in high income cases (high level of ultimate wealth, buy lottery tickets). In the domain of road traffic this describes the conflict between the aversion against risks (accidents and its consequences) and risk taking (high speeds in order to save time). FRIEDMAN and SAVAGE's analysis primarily considered different valuations of positive and negative pay-offs.²

Many authors investigated the second element of expected utility theory, **probabilities** and their valuation in the theory. ALLAIS (1953) found a discrepancy between objective and subjective probabilities. The so called **ALLAIS paradox** leads to a violation of the independence axiom. ELLSBERG (1961) discussed whether all **uncertainties** can be reduced to **risks**. Risk was defined as a qualitative or quantitative probability which means that it can sufficiently be fixed. He found that theories describing uncertainty in terms of probabilities are not applicable since individuals do not always assign probabilities to uncertain events.

¹ MACHINA (1982) introduced the term *generalized expected utility analysis* for advancements and new approaches in expected utility theory (see also SUGDEN, 1986). ARROW (1982) summarized individual behavior under uncertainty in several economic domains. His analysis stressed some violations of the axioms mentioned in earlier papers (see also SLOVIC and TVERSKY, 1974). WEBER and CAMERER (1987) and CAMERER (1989) reviewed expected utility theory and some other approaches concerning individual behavior under uncertainty.

² An analysis of the differences in the payoffs in the context of expected utility theory was also performed by HANSSON (1975). He explicitly understood utility as a function of changes in wealth rather than as a function of levels of wealth. This concept was introduced earlier by MARKOWITZ (1952).

It is, therefore, impossible to derive utility functions as suggested by VON NEUMANN and MORGENTHAU (1944). MACCRIMMON (1968) found that individuals will prefer the risky game of an explicitly given 50-50% chance against the uncertain game where no probabilities are given even if this still implies the same chance of 50-50%.³

In the context of expected utility theory individuals choose their behavior such that it maximizes the expected utility. The theory pronounces the economic rationality of decisions. In numerous papers dealing with behavioral decision research it was shown that the theory formulated by VON NEUMANN and MORGENTHAU (1944) is frequently violated. Particularly the axioms transitivity, continuity, and independence hold only under specific conditions. TVERSKY and KAHNEMAN (1986) judged "the theory ... as a normative model of an idealized decision maker, not as a description of the behavior of real people" (p. 251).

8.2 Prospect Theory

Prospect theory is a concept of behavioral decision research describing individual behavior under uncertainty (see KAHNEMAN and TVERSKY, 1979). Reviews with numerous intuitive examples were given by THALER (1991b) and EDWARDS (1996). Also, HEATH ET AL. (1999) investigated individual behavior and individual goals within a prospect-theoretical frame. Below we introduce the basic framework of the theory.

Prospect theory (KAHNEMAN and TVERSKY, 1979) proposes a framework to explain risky choices of individuals. This framework accounts for many deviations of human behavior from the axioms of expected utility theory in decision-making processes. The theory also takes inconsistencies into account during the individ-

³ This misperception of probabilities may lead to a subjective probability valuation which does not sum up to unity for mutually exclusive events. For this reason FELLNER (1961) as well as HANSSON (1975) introduced a correction factor for such probabilities. The difference between the expected utility in the theory and the utility subjectively realized by the individual was called utility of gambling (FELLNER, 1961).

ual decision-making process. A prospect (x_i, p_i) consists of an outcome x_i and its probability of occurrence p_i , where $p_1 + p_2 + \dots + p_n = 1$. Riskless prospects are denoted by (x) . The process of decision-making consists of two phases. In the **editing phase** the offered prospects are mentally represented. In the subsequent **evaluation phase** the edited prospects are rated. Finally, the prospect of highest subjective value is chosen. The following major operations guide the editing of the outcomes.⁴ They are based on various empirical studies, e. g., by MARKOWITZ (1952), FELLNER (1961), and HANSSON (1975).

1. **Coding:** Individuals base their decisions on the expected change in wealth (gains and losses). Thus, they have to compute their neutral reference point prior to their decision. That point usually corresponds to their current asset position.

Given the sample mentioned in chapter 8.1, the manager evaluates only gains and losses of the various travelling modes. His current asset position may be interpreted as his current residence. He can go to the meeting starting (a) from his office or (b) from his holiday resort.

2. **Combination:** Prospects are combined to simplify the decision process. The prospect (100, 0.2; 100, 0.2) can be combined to (100, 0.4).

The above-mentioned travelling modes, the lotteries A , B , and C , can be interpreted as already combined prospects. When the manager evaluates C (travelling by car), he may have already combined the probabilities that he has an accident by (a) hitting a tree or (b) overturning with his car. Both accident types may have fatal consequences.

3. **Segregation:** Prospects sometimes contain riskless components (gains or losses). These are segregated from the risky components. The prospect

⁴ Similar editing rules were stated by THALER and JOHNSON (1991).

(100, 0.2; 200, 0.8) equals a combination of a riskless gain (100) and a risky prospect (100, 0.8).

Let us assume that the manager has to decide whether he attends the meeting at all. If he does not attend he will realize a loss by losing information. This loss even exceeds the price of the plane ticket which is assumed to be the most expensive travelling mode. Regardless whether he attends the meeting or not, *ex ante* he already knows that he will lose not less than the price of the cheapest ticket. If he travels he will have to pay this price at least. If he does not travel he will lose the even more valuable information. *Ex ante* the cheapest ticket can already be interpreted as a sure loss.

4. **Cancellation:** Some prospects can share components. These components are ignored in decision-making processes.

Let us assume that the "ticket" costs of travelling by car consist only of the needed fuel. The plane ticket as well as the train ticket are more expensive. If the manager decides to attend the meeting he will at the very least lose the fuel costs. This sure loss can be ignored in the lotteries *A* and *B*. He only has to take into account those plane/train ticket costs exceeding the fuel costs in lottery *C*.

5. **Simplification:** Prospects are simplified by rounding probabilities or outcomes. The prospect (101, 0.49) may be simplified to (100, 0.5). Extremely unlikely outcomes are discarded (e. g., (100, 0.0001)).

The manager may calculate quite rough figures. If he calculates the saved time of each travelling mode he will not be interested in the saved minutes, but in the saved hours.

6. **Detection of dominated strategies:** The remaining prospects are detected for dominated prospects. These are eliminated.

The manager chooses the travelling mode by the comparison of the crash risks, the ticket price, and the saved time. Assume that he

equalizes the crash risks of the plane and those of the train. The crash is associated with a fatality in both cases. The ticket price is also the same in both travelling modes (economy class plane ticket versus first class train ticket). If the plane saves more time than the train he never takes the train to travel to the meeting. In this case travelling by plane dominates over travelling by train.

The remaining set of prospects after the editing phase is not predetermined. It depends on the sequence of the applied editing rules. Contrary to expected utility theory, inconsistent preferences may occur due to the application of these rules.

In the second phase the remaining prospects are evaluated. Each prospect is assigned a value and the best valued prospect is chosen. This evaluation phase consists of several steps. First, any objective probability p_i is assigned a subjective value $\pi(p_i)$. Usually there is $\pi(p_i) + \pi(1 - p_i) < 1$ (HANSSON, 1975). Second, any objective payoff x_i is assigned a subjective value $v(x_i)$ depending on the predetermined neutral reference point.

With respect to the two components of a prospect, payoffs (gains and losses) and probabilities, KAHNEMAN and TVERSKY (1979) suggested two curvatures in order to describe the editing and the evaluation phase. These are (a) the **value curvature** and (b) the **weighting curvature**.

The shape of the value curvature (figure 8.1) is determined by the different perception of gains and losses. Symmetric lotteries $(x, 0.5; -x, 0.5)$ are unattractive to individuals. The more the amount of x increases the more they become unattractive. The absolute value of a gain x is higher than the absolute value of a loss x . The aversion to a loss of x is higher than the preference to a gain of x .⁵ The rise of the value curvature is steeper for losses than for gains.⁶ The valuation of payoffs depends on their absolute level. Even if the absolute difference is the

⁵ It explains the hard work of young scientists in writing their PhD thesis. One needs individual subgoals in order to complete the thesis in time (e. g., finish the current chapter by the end of this week). These subgoals imply the possibility of failure. This is much more unpleasant than the enjoyment of reaching the goal in an unspecified period of time (see for similar examples HEATH ET AL., 1999).

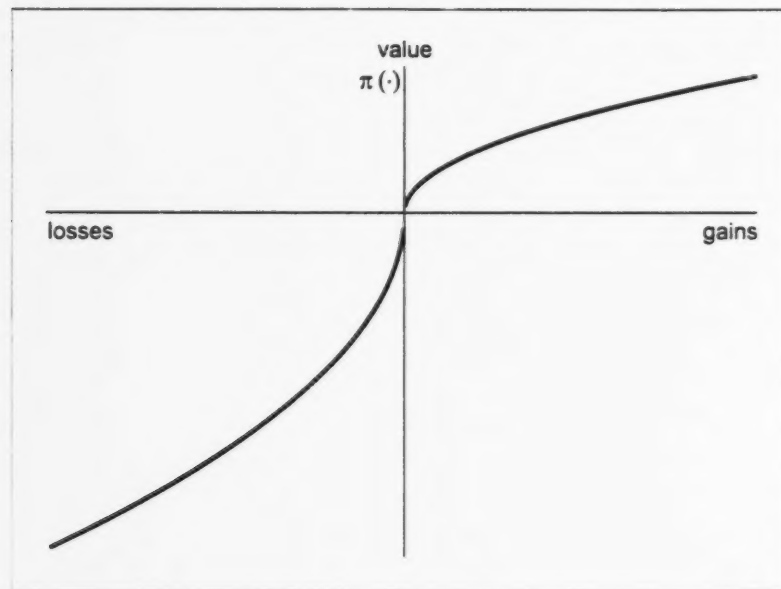


Figure 8.1: Value curvature, source: KAHNEMAN and TVERSKY (1979, p. 279)

same a gain of 200 compared to 100 will be more favorable than a gain of 1200 compared to 1100. The same holds for losses respectively. The value curvature is non-linear in gains as well as in losses. It is concave in case of gains and convex in case of losses.⁷

The weighting curvature (figure 8.2) assigns individual weights to real probabilities. Impossible events are discarded ($\pi(0) = 0$) and riskless events are weighted with the maximum ($\pi(1) = 1$). Contrary to expected utility theory, there exists no linear function between probabilities and weighted probabilities within the interval $[0; 1]$. Small probabilities are over-weighted. The weighting curvature is subadditive: $\pi(rp) > r\pi(p)$, $0 < r < 1$. A gain of 1000 with probability 0.002 is valued higher than twice this gain with half the probability.⁸

⁶ This phenomenon was already mentioned by MARKOWITZ (1952).

⁷ The implications of such a shape within a marketing context were analyzed by THALER (1985).

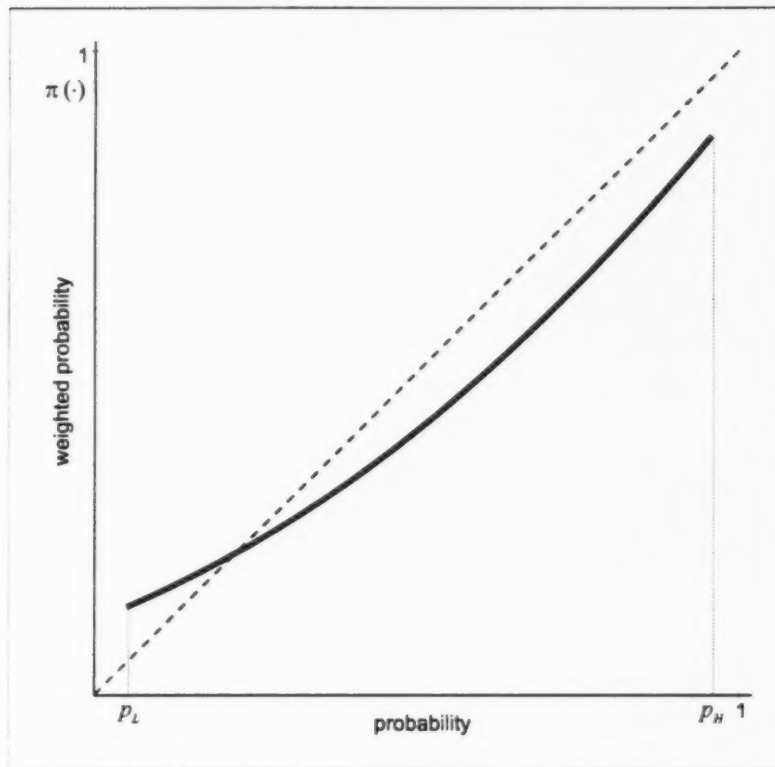


Figure 8.2: Weighting curvature, source: KAHNEMAN and TVERSKY (1979, p. 283)

Close to its boundaries 0 and 1 the weighting curvature is discontinuous. In case of very unlikely events the valuation of probabilities depends on the individual ability to assign a $\pi(p)$ to a p close to zero. Below a threshold p_L there is $\pi(p) = 0$. The same holds for very likely events. Above a threshold p_H there is $\pi(p) = 1$. Hence, the prospect is considered as riskless. The thresholds p_L and p_H vary

⁸ Well known applications of this behavior are lottery tickets and insurance policies. In the first case individuals prefer a very unlikely but high gain. Insurance policies protect against very unlikely but high losses. In both cases the very small probability to win (lottery ticket) or to lose (insured event) is overestimated. In terms of expected utility theory the individuals will be indifferent between the risky and the riskless alternative if the price of a lottery ticket or an insurance policy is fair. Because of the profits of lottery organizations and insurance companies this is usually not the case.

between different decision-making processes.

Below we will discuss explanations of individual behavior based on the concepts of prospect theory.⁹ THALER (1980) examined some explanations of individual behavior formalized by KAHNEMAN and TVERSKY (1979). First, he identified the **endowment effect**. Those goods already included in individuals endowment are higher valued than other goods not yet part of this endowment. Removing a good from the endowment bundle generates a loss. This is higher valued than the produced gain if the same good is added to the endowment bundle. On the one hand, the difference can be attributed to the different valuation of out-of-pocket costs and, on the other hand, to opportunity costs. The latter do not lead to a cash payment. Opportunity costs are, therefore, undervalued compared to the same amount of out-of-pocket costs.¹⁰

Assume that the manager in our sample has already bought a train ticket a few days ago. He did not realize that there is a plane which would save him five hours as compared to the train. Even if the opportunity costs of these five hours largely exceed the price of the already bought train ticket plus the price of a plane ticket the manager will probably not revise his decision to travel by train. The train ticket is already part of his endowment. It would become useless if he goes by plane. An additional plane ticket would lead to out-of-pocket costs. These are higher valued than the opportunity costs of the five hours.¹¹

⁹ Other applications of the prospect theory in various contexts can be found by CONSTANTINIDES (1984), SHEFRIN and STATMAN (1985), FERRIS ET AL. (1988), FIEGENBAUM and THOMAS (1988), FIEGENBAUM (1990), COLLINS ET AL. (1991), and SINHA (1994). Besides these applications the theory itself was enhanced by various concepts, like the non-linearity of the weighting curvature (QUIGGIN, 1982), the non-additivity of probabilities (SCHMEIDLER, 1989), and the explicit distinction between gains and losses in the weighting curvature (TVERSKY and KAHNEMAN, 1992, see also WAKKER and TVERSKY, 1993; CHATEAUNEUF and WAKKER, 1999).

¹⁰ Further experiments to the endowment effect were reported by KAHNEMAN ET AL. (1990) and TVERSKY and KAHNEMAN (1991).

¹¹ This behavior can also be explained by *mental accounting* (TVERSKY and KAHNEMAN, 1981; KAHNEMAN and TVERSKY, 1984; THALER, 1985, for an application in the domain

Other biases in decision making are **regret** and **pre-commitment** (THALER, 1980). The former becomes obvious in the field of health care. Decisions involving tradeoffs between money and health care are very unpleasant. People would regret that they decided not to take a therapy once a serious disease occurs. This holds even if the probability to contract the disease is very close to zero (THALER, 1980, p. 53). Pre-commitment is one possible explanation for the sunk cost effect.¹² People are precommitted to their historical investments, like voluntary investments in education. In this case the sunk investment leads to its frequent use.¹³

The manager may take into consideration the historical costs of his own car when he decides about the travelling mode. He is precommitted to this sunk investment. These costs are already paid and they cannot be saved regardless of his decision. They should, therefore, be irrelevant for the decision process.

A further phenomenon which influences an individual's judgments is the **framing** of decisions (see, e. g., KAHNEMAN and TVERSKY, 1979; 1984; THALER, 1980; TVERSKY and KAHNEMAN, 1981; 1986).¹⁴ Depending on the given description of the prospects, people construct their own representations of these prospects. If a prospect contains uncertain gains as well as uncertain losses the preference for this prospect highly depends on the (verbal) representation of both parts. If the loss is more pronounced than the gain then the prospect appears unfavorable. If

of economics see SIEFRIN and STATMAN, 1985). Since the manager already paid for the train ticket the account "travel to the meeting" is already charged by this ticket price. An additional plane ticket would charge this account in an unacceptable manner. In this case the price of the trip would consist of the sum of both ticket prices.

¹² The sunk cost effect refers to the relevance of historical costs in an individual's decisions (see also KAHNEMAN and TVERSKY, 1979). A review about the sunk cost effect in an economic context was given by SCHIAUB (1996).

¹³ Another expression for pre-commitment is *self-control* (THALER and SIEFRIN, 1991).

¹⁴ The effect of various representations of a single event was already mentioned by TVERSKY and KAHNEMAN (1974).

the accentuation changes in favor of the gain then the preference for this prospect increases.

Assume that the manager has to decide about the travelling mode right after a disastrous air plane crash. In this case the risks of flying are more pronounced in mass media. These risks become explicit to the manager. Thus, prospect *A* (travelling by plane) becomes less favorable, since most accentuation is given to the uncertain losses (crash) of this travelling mode.

These phenomena endowment effect, regret, pre-commitment, and framing are interpreted as biases in the human decision-making process under uncertainty. They will be also relevant in the domain of road traffic (see chapter 9.4).

8.3 Support Theory

In contrast to expected utility theory and prospect theory, support theory does not refer to any payoff; it only considers probability judgments of uncertain events. Conventional BAYESIAN models describe the generation and the revision of probability judgments by individuals as soon as new evidence arises in uncertain events. Those models and the so called revisionist models (TVERSKY and KOEHLER, 1994) are based on the same basic principle, the extensionality principle: probability judgments are independent from the given description of an event. The consequence of any description, their extension, is always the same. If the extension of the event *A* includes the extension of the event *B*, i. e., $A \supset B$ then $Q(A) \geq Q(B)$, while *Q* refers to the probability of the occurrence of an event.¹⁵

¹⁵ Based on an empirical analysis the extensionality principle was rejected by TVERSKY and KAHNEMAN (1983). They asked one group of subjects to estimate the number of seven-letter words ending with *ing* in a given text. A second group was asked to estimate the number of seven-letter words with the letter *n* in the sixth position in the same text. In this task the second question is included in the first one. Following conventional theories, the

In turn, TVERSKY and KOEHLER (1994) introduced the concept of **non-extensionality**. They distinguished between two sources of non-extensionality, **memory limitations** and **different descriptions** of the same event. The former occurs since individuals do not recall all instances of a category in their judgments. An explicit description of all relevant occasions avoids this effect. Different descriptions of the same event call attention to different aspects of the outcome. This affects the judged probability of the event and, thus, extensionality fails.

Some of the just mentioned aspects are already stated in prospect theory. For example, the framing effect contains the concept of different descriptions of the same event. Nevertheless, TVERSKY and KOEHLER (1994) suggested a new theoretical framework, the support theory, for pronouncing further relevant aspects of an individual's decisions under uncertainty.¹⁶ Given the principle of non-extensionality, support theory also accounts for inconsistencies in human decision processes.

TVERSKY and KOEHLER (1994) distinguished between a finite set T of events including at least two elements being interpreted as the states of the world, and a finite set H of descriptions of these events called **hypotheses**. Each hypothesis $A \in H$ corresponds to a unique event $A' \subset T$. Two different hypotheses A and B may have the same extension, i. e., $A' = B'$. In that case both hypotheses refer to the same event. There exists at least one hypothesis for each event.

The manager thinks about the risk of a crash in each of the three travelling modes. The states of the world (events) might be: (a) arrive with no crash and (b) crash. If we consider the mode "travelling by car" hypotheses of the second event (crash) may be (a) hit a tree, (b) overturn

estimator of the second group should be greater or at least equal to that of the first group. The experiment lead to the reverse result. The estimator of the first group was three times higher than that of the second group. It seemed to be easier to imagine a seven-letter word ending with *ing* than a seven-letter word with the letter *n* in the sixth position. The judged probability was *not* independent from the given description of an event. Other examples of this phenomenon were stated by FISHHOFF ET AL. (1978) and JOHNSON ET AL. (1993).

¹⁶ Further developments of this theoretical concept can be found by KOEHLER ET AL. (1997) and BRENNER and KOEHLER (1999).

with the car, (c) collision with another car, (d) fractures, and (e) fatality.

The hypotheses A and B are exclusive if $A' \cap B' = \emptyset$. If $A, B \in H$ and A and B are exclusive then $(A \vee B) \in H$. $A \vee B$ is the **explicit disjunction**. It is assumed that $(A \vee B)' = A' \cup B'$.

Assume that two hypotheses exist regarding the event "crash" if the manager travels by plane: (a) the plane crashes due to an exploding bomb and (b) the plane crashes due to a technical defect. Only one of these hypotheses can be true in case of a crash, which means that both hypotheses are exclusive. If the manager has both possible consequences of a crash in mind this is called an explicit disjunction.

Beside the explicit disjunction there exists the **implicit disjunction**, also called the implicit hypothesis. A is an implicit hypothesis if $A' = (B \vee C)'$. $B \vee C$ is the explicit disjunction.

If the manager travels by plane, assume that the event "crash" either comes from (a) an exploding bomb or (b) a technical defect. Then the implicit hypothesis "aircrash" consists of the explicit disjunction "exploding bomb" $\vee$ "technical defect".

The **evaluation frame** (A, B) consists of a pair of exclusive hypotheses: the **focal hypothesis** A and the **alternative hypothesis** B . The focal hypothesis is evaluated by the judging individual. The individual perceives the mutual exclusivity of A and B , which means that only one of these events can occur. A probability judgment is a mapping Q from the evaluation frame to the unit interval. $Q(A, B)$ is the probability judgment that A rather than B holds, assuming that only one of them is valid.

Assume that the two hypotheses no longer refer to the same extension. The focal hypothesis A "accident" refers to the extension A' "crash",

while hypothesis B "arrive to the meeting on time" refers to B' "no crash". The manager now judges the probability $Q(A, B)$ that he has an accident rather than that he arrives to the meeting.

A value of **support** s is assigned to each hypothesis in H .

$$Q(A, B) = \frac{s(A)}{s(A) + s(B)} \quad (8.2)$$

The "judged probability is interpreted as the support for the focal hypothesis A relative to the alternative hypothesis B " (FOX, 1999, p. 168). The following relation refers to the fact that the support increases if explicit disjunctions are formulated instead of a (single) implicit disjunction. This is called **unpacking effect**.

$$s(A) \leq s(B \vee C) = s(B) + s(C) \quad (8.3)$$

B and C are exclusive, A is implicit, and $A' = (B \vee C)'$ (TVERSKY and KOEHLER, 1994). Two reasons explain this unpacking effect. First, the explicit formulation reminds people of possibilities they may have overlooked. Second, the salience of an event and, hence, its perceived support increases if various consequences are explicitly mentioned (FOX, 1999, pp. 168).

The support for the hypothesis A , "accident", increases as soon as some explicit disjunctions come to mind, like "having a fractures" or "fatality". If the manager becomes aware of such explicit disjunctions he judges the probability of an accident higher than if he only has in mind the implicit disjunction "accident".

The unpacking principle implies **sub-additivity** which is expressed on the left hand side of the inequality (8.3). The judged probability of A is less than or equal to the sum of the judged probabilities of its components B and C .¹⁷ ROTTENSTREICH and TVERSKY (1997) distinguished between **implicit sub-additivity**

(left hand side of the inequality (8.3)) and **explicit sub-additivity**. The latter becomes obvious if we separately judge the probabilities of the components of an explicit disjunction. This leads to $s(B \vee C) \leq s(B) + s(C)$ (see also FOX, 1999).

ROTTENSTREICH and TVERSKY pointed out that additivity is not required in support theory. It is violated particularly in more complicated settings with more than two hypotheses. In simple settings with two mutually exclusive hypotheses A and B , it is obvious that B is the same as $\bar{A}$. ROTTENSTREICH and TVERSKY investigated two mechanisms producing explicit sub-additivity. First, **repacking**, i. e., summarizing several hypotheses to one implicit disjunction, leads to sub-additivity. The second source of explicit sub-additivity is **anchoring and adjustment**. The judge evaluates only one of the components and adjusts this value upward to accommodate the other components.¹⁸

The manager may not be able to distinguish among all possible consequences of a road accident, unless they are explicitly presented. He may have repacked these consequences into one general hypothesis: "having an accident". If he has an idea about his general road accident risk he may use this figure to compute other less conceivable risks like "sustaining fractures" or "having a fatality".

8.4 Summary of the Theoretical Concepts

In table 8.1 the main concepts of expected utility theory, prospect theory, and support theory are summarized and contrasted to risk homeostasis theory. The comparison is conducted with various aspects. Risk homeostasis refers to acci-

¹⁷ The more general non-additivity phenomenon is already mentioned above in the discussion of the two other theoretical concepts. Empirical evidence of sub-additivity in various contexts was documented by FISHHOFF ET AL. (1978), DUBE-RIoux and RUSSO (1988), TVERSKY and KOEHLER (1994), and AYTON (1997).

¹⁸ Such adjustments are generally insufficient in terms of rationality as already mentioned by TVERSKY and KAHNEMAN (1974) and POULTON (1994).

dent risks, while the other three concepts consider the underlying decision-making process. Consequently, target risk and perceived risk are compared in risk homeostasis theory. In the context of the three behavioral theories decisions are based on probabilities for uncertain events (expected utility theory) or their perception and valuation (prospect theory and support theory). Expected utility theory as well as prospect theory also consider the effects of incentives (payoffs) in the individual decision-making process.

Behavior will be adjusted in risk homeostasis as soon as differences between the target and perceived risk occur. In the behavioral theories the decision principle is based on expected assets (expected utility theory) or on expected gains (prospect theory), while the accompanied risks constitute only one part. Since support theory only considers the evaluation of probabilities, the behavioral decision is only determined by the individual's probability judgment for an uncertain event. A specific decision principle can therefore not be deduced.

Table 8.1: Comparison of the basic concepts of the four theories

theory	risk homeostasis	expected utility	prospect	support
fundamental principle	constant accident risk	economic rationality	biased perception and valuation of payoffs and probabilities	non-extensionality of hypotheses
main objective	accident risks with respect to time of exposure	decisions under uncertainty		judging uncertain events
comparison objects	target and perceived risk	lotteries	prospects	hypotheses
decisional frame	global accident risk	uncertain events in specific situations		
input parameters	risk	payoff, probability	edited and weighted payoff and probability	focal and alternative hypotheses
decision principle	equalization of target and perceived risk	maximization of expected final asset position	maximization of expected gains	
outcome	behavioral adjustment	selection of a specific behavior (lottery)		judgment of the probability of the focal hypothesis

Chapter 9

Models of Human Behavior in Road Traffic

Based on the theoretical concepts introduced in chapter 8 we present a model of an individual's behavior in road traffic. A traffic accident is assumed to be an **uncertain event** since its occurrence is not predictable. It depends on the individual driving behavior. People have to adapt their behavior such that they, on the one hand, avoid an accident and, on the other hand, maximize their payoff from driving.

The analysis goes as follows. First, we classify the considered safety measure, the intensified seat belt legislation in Germany of August, 1984. Second, the general framework of the model is outlined. Third, we specify the decision-making process of the driver within the three theoretical concepts introduced in chapter 8. Finally, a summary is given and some general conclusions are drawn.

9.1 Classification of Safety Measures

Safety measures in road traffic contain a wide variety of aspects:

1. mandatory versus voluntary safety measures (speed limit versus ABS)

2. perceivable versus non-perceivable safety measures (speed limit versus improvements of the resistance against frontal crashes)
3. safety measures decreasing accident frequency versus safety measures decreasing accident severity (ABS versus airbag)
4. safety measures decreasing an occupant's risks versus safety measures decreasing a pedestrian's/bicyclist's risks (airbag versus zebra crossing)
5. technical versus behavioral safety measures (ABS versus speed limit)

The exact classification of a safety measure is not always possible. It is, for example, not obvious whether a speed limit primarily decreases accident frequency or accident severity; it probably affects both. Thus, the five above-mentioned aspects overlap in some occasions. Below we investigate the effects of the seat belt usage in Germany. This safety measure is classified as follows. Prior to August, 1984, any car in Germany was at the very least equipped with seat belts in the front seats since seat belt legislation came into effect in 1976. Driving unbelted was, however, not punished until August, 1984. The seat belt usage was a **voluntary** safety measure before this date. It became a **mandatory** measure after this date. Furthermore, it is **perceivable** and it leads to a decrease in **accident severity** (see chapter 4.1.2). The seat belt primarily protects **car occupants**. Finally, it is a **behavioral** safety measure. Even if seat belts are installed in a car it is not sure that they will be used.

Below we only refer to an individual's decision-making processes in road traffic. This implies that at least two behavioral alternatives must exist. Because of (a) the classification of seat belt usage and (b) the considered decision-making processes the investigation cannot be easily generalized. Sometimes decision alternatives are simply missing. For example, today it is impossible to buy a new car in Germany which is not equipped with an airbag even if this equipment is not mandated.

9.2 The Framework of the Model

Below we outline the basic features of our model. It is based on lotteries as already introduced in expected utility theory and prospect theory. As we will see below, it is possible to construct a similar lottery framework in driving behavior and safety measures. In the following section lotteries relate to individual behavior in a specific context. People make a decision, choose a lottery, and, thus, they choose their individual driving behavior. Since such lotteries consist of a payoff, which is not considered in support theory, the model has to be readjusted.

9.2.1 Individual Behavior in Different Contexts

People can choose their **behavior** in two ways. First, they can behave in accordance with the safety measure, which means, for example, that they use the seat belt. Second, they can disregard the safety measure. We distinguish between two **contexts**, (a) the presence and (b) the absence of a penalty. The former refers to the case that people choose their behavior when they are confronted with a penalty for non-compliance with a mandatory safety measure. The latter means that they take their behavioral choice in absence of a penalty. We get a 2×2 matrix as shown in table 9.1.¹

Table 9.1: 2×2 matrix

		context	
		penalty	no penalty
behavior	compliance with safety measure	I	II
	non-compliance with safety measure	III	IV

Case (I) describes the situation where individuals behave in accordance with the traffic rule in the presence of a penalty. In case (II) individuals already behave

¹ Note that the safety measure is the seat belt. Thus, we have to distinguish between this measure and the possible additional penalty for non-compliance with the measure.

in accordance to a safety measure in the absence of a penalty. Thus, no further decisions are necessary by the legislator about additional penalties. In case (III) individuals do not comply with the safety measure despite of an existing penalty. In our context case (IV) is of most interest. Individuals do not realize the positive effects of the safety measure in question (e. g., seat belt usage). We will analyze in which way individuals decide their behavior. We will also investigate the circumstances leading to a behavioral change by a change of the context.

Let us formulate the corresponding lotteries in the 2×2 matrix. We have to consider four lotteries, two in each context. We get the matrix as shown in table 9.2. There "c" refers to "compliance with the safety measure", while "p" refers to "penalty".

Table 9.2: 2×2 matrix and lotteries

		context	
		penalty	no penalty
behavior	compliance with safety measure	L'_p	L'
	non-compliance with safety measure	L_p	L

Based on the above-mentioned theoretical concepts we need several descriptions of the same lottery. In the context of expected utility theory final asset positions are considered, while prospect theory deals with changes in the asset position starting from a neutral reference point. As already mentioned, asset positions are not considered in support theory. All three theories are, however, based on probabilities or the evaluation of probabilities. We start with an analysis of several asset positions and their changes followed by an investigation of the considered probabilities in the decision-making process.

9.2.2 Asset Positions, Probabilities, and Their Changes

In the model we analyze the effects of a new or of an intensified safety measure given the **status quo** at the date of its introduction. This is similar to a *ceteris paribus* investigation in economics.

The **final asset position** in status quo is denoted by x (case IV in table 9.1). In this case individuals do not voluntarily comply with the safety measure. x is the individually owned asset prior to the change in the context and, thus, prior to the introduction of a penalty. **Changes in asset positions** do, therefore, not yet occur, i. e., $\Delta x = 0$. x is the reference point of an individual's decisions in terms of the expected utility theory.

Let us assume that it is possible for the individuals to voluntarily behave in compliance with the safety measure. For example, they can voluntarily use the seat belt, and observe a recommended speed limit. If individuals voluntarily comply with the safety measure in the context of no penalty (case II in table 9.1) then the asset position x changes to x' . This leads to $\Delta x' = x - x'$ in terms of changes in asset positions.

Assume that a penalty exists, it is never paid if the individual complies with the safety measure (case I). Thus, this case is equal to the just considered case (II). The final asset position (x') as well as the change in the asset position ($\Delta x'$) are the same in both cases.

Even in the context of an existing penalty the individual may not comply with the safety measure (case III in table 9.1). In this case we get the final asset position $x_p = x - e$ if the penalty is actually paid. Otherwise the asset position x is obtained which is equal to the status quo. With respect to the changes in asset positions we get either e in case of an actually paid penalty or the status quo if the penalty has not been paid. The asset positions mentioned and their changes are shown in table 9.3. These figures refer to the case where no accident occurs.

If an accident occurs and the driver is unbelted (case IV) then we denote the average asset position by y (see table 9.4). In terms of changes there is $\Delta y = x - y$. Individuals achieve the asset position y in the case of an accident, which means that they suffer a loss of Δy as compared to the status quo.

If the safety measure is observed the final asset position y' as well as the loss $\Delta y'$ are the same regardless whether a penalty exists (case I) or not (case II). Since

Table 9.3: 2×2 matrix, asset positions, and their changes in case of no accident

			context	
			penalty	no penalty
behavior	compliance with	final asset	x'	x'
		change	$\Delta x'$	$\Delta x'$
	non-compliance	final asset	$x_p \vee x$	x
		change	$e \vee \Delta x = 0$	$\Delta x = 0$

the driver is belted in our specific case, the asset y' exceeds y , which means that the loss $\Delta y'$ is smaller than the loss Δy . In case (III) the final asset position y_p is obtained in the case of an accident. This case is denoted by Δy_p in terms of losses. y_p exceeds y by the amount of the penalty. The same holds for Δy_p . Also Δy_p exceeds Δy by the amount of the penalty.

Table 9.4: 2×2 matrix, asset positions, and their changes in case of an accident

			context	
			penalty	no penalty
behavior	compliance with	final asset	y'	y'
		change	$\Delta y'$	$\Delta y'$
	non-compliance	final asset	y_p	y
		change	Δy_p	Δy

So far, we introduced various figures measuring payoffs (a) within different contexts and (b) after the occurrence of different events. We did not yet discuss the second component of the lotteries, the **associated probabilities**. Contrary to payoffs these are judged in support theory. The compliance or the non-compliance with the safety measure does not affect the accident frequency risk τ of the individual since we assume that accident frequency remains constant due to the intensification of the seat belt legislation (see also the empirical results in chapter 6.5). We further introduce a second risk measure p which denotes the probability

that the individual has to pay the penalty if any exists. We get the considered probability measures as shown in table 9.5.

Table 9.5: 2×2 matrix of the considered probability measures

		context	
		penalty	no penalty
behavior	compliance with safety measure	r	r
	non-compliance with safety measure	$r \wedge p$	r

9.3 Driving Behavior within the Context of Expected Utility Theory

9.3.1 Expectations in the Absence of a Penalty

Within the context of expected utility theory we analyze final asset positions. This theory is based on the rationality of decisions. The installation of seat belts in cars is associated with the assumption that their usage increases the final asset position in case of an accident.² The associated utility relation is given by $u(y') > u(y)$. Belted individuals may realize a smaller utility than unbelted individuals if no accident occurs. This can be attributed to the more frequent occurrence of light injuries (see, e. g., CAMERON, 1981). Such injuries are completely prevented if occupants are unbelted. The smaller utility also results from feeling less comfortable while wearing the belt. Both reasons lead to the utility relation $u(x') < u(x)$. This disutility of a belted driver, if no accident occurs, is smaller than the utility from the prevention of the most severe accidents. Otherwise, seat belt usage cannot be recommended by any rational argument. We, therefore, get $|u(x) - u(x')| < |u(y) - u(y')|$, which means that

² The installation of seat belts in cars is intended to prevent severe consequences of an accident, like fatalities. This is already discussed in chapter 4.1.2 (see also GRIME, 1979; JONAH and LAWSON, 1984; ADAMS, 1994).

individuals should voluntarily use the seat belt. Finally, we predict a preference relation as follows:

$$L' \succ L \quad (9.1)$$

This preference relation results from the intended rational behavior if such a safety measure is propagated and introduced. Nevertheless, until the beginning of the 1980's the belt usage rate in Germany was less than 50% in urban areas (DIW, 1988, p. 135; DIW, 1993, p. 150). A substantial proportion of drivers did not reveal preferences as predicted. This bias will be discussed in chapter 9.3.3.

9.3.2 Expectations in the Presence of a Penalty

After the introduction of a penalty (change in the context) unbelted driving becomes even less preferable:

1. Because of the penalty, the utility $u(y_p)$ is less than $u(y)$ in the case of an accident. If belted $u(y')$ is always achieved in the case of an accident. Even if a penalty exists it is never paid. There is $|u(y') - u(y_p)| > |u(y') - u(y)|$. In the case of an accident the preference for driving belted **increases** as soon as a penalty is introduced.
2. If the driver is unbelted and no accident occurs then we get $u(x_p) < u(x)$. Thus, if the penalty has to be paid and x_p is achieved then this is less preferred than the status quo. Nothing changes if the driver is belted and the penalty never has to be paid. In this case $u(x')$ is always achieved in the case of no accident. Thus, there is $|u(x_p) - u(x')| < |u(x) - u(x')|$. In the case of no accident the preference for driving unbelted **decreases** as soon as a penalty is introduced.

Given (9.1), the preference relation in the case of no penalty, we predict the following preference relation if a penalty exists:

$$L'_p \succ L_p \quad (9.3)$$

The lottery "driving unbelted" becomes even less preferable. This is frequently observed in road traffic since belt usage rate increased to more than 95% after the introduction of the penalty in Germany in August, 1984 (DIW, 1988, p. 135; DIW, 1993, p. 150). A small proportion of drivers, however, further disregard the safety measure. Below we investigate this phenomenon in the context of expected utility theory, and we present some explanations.

9.3.3 Concluding remarks

In the absence of a penalty individuals have to decide between two lotteries, $L(x, (1-r); y, r)$ and $L'(x', (1-r); y', r)$. We frequently observe non-compliance with the safety measure, which means that there is

$$L \succ L' \quad (9.4a)$$

$$(1-r)u(x) + ru(y) > (1-r)u(x') + ru(y') \quad (9.4b)$$

Given (9.4b) two sources for this behavior arise. These are the valuation of (a) probabilities and (b) utilities (payoffs). Both valuations may differ from the rational expectations in expected utility theory. Since the probability r of having an accident is the same in both lotteries the behavior of driving unbelted results from a biased valuation of payoffs.

Individuals may not be able to specify the advantage of seat belt usage in a specific accident. Seat belt wearing particularly decreases accident severity. The perception of such a decrease is less likely than the perception of a decrease in accident frequency (GRAHAM, 1982; SAGBERG ET AL., 1997). Individuals may be unable to perceive $u(y') > u(y)$. In this case the integrity axiom is violated. Based on expected utility theory we would predict that $u(y') > u(y)$, but individuals may evaluate that $u(y') = u(y)$. In turn, the disutility of being unbelted $u(x') < u(x)$ is immediately realized. This disutility is assigned to "no accident", which is usually the case in the everyday life. The aversion against disutilities further explains the revealed preferences of the individuals (see FRIEDMAN and SAVAGE, 1948; HANSSON, 1975).

Due to the introduction of a penalty more than 95% of the car occupants prefer belt usage over driving unbelted. The revealed preferences by most of the individuals are now equal to the theory-based predictions in (9.3). In this context lotteries change to $L_p(x, (1-r-p); x_p, p; y_p, r)$ and $L'_p(x', (1-r); y', r)$. If driving unbelted the additional event "pay the penalty and achieve asset x_p " is added. It occurs with the probability p :

$$L_p \prec L'_p \quad (9.5a)$$

$$(1-r-p)u(x) + pu(x_p) + ru(y_p) < (1-r)u(x') + ru(y') \quad (9.5b)$$

The left hand side of (9.5b) contains the term $(1-r-p)u(x) + pu(x_p)$ instead of $(1-r)u(x)$ in (9.4b). Since $x_p < x$ and $p > 0$, there is $(1-r-p)u(x) + pu(x_p) < (1-r)u(x)$. Furthermore, y_p in (9.5b) is less than y in (9.4b). Thus, there is $ru(y_p) < ru(y)$.

The expected penalty is sufficient to obtain the intended behavior. The penalty induces most of the individuals to fasten the seat belt. Unbelted driving is explicitly associated with a potential low level of ultimate wealth. Individuals prefer insurance in such cases. They drive belted in order to prevent this low ultimate wealth (FRIEDMAN and SAVAGE, 1948). The price for this insurance is the inconvenience of wearing the belt. The belt also causes some minor injuries in the case of an accident which would be prevented by driving unbelted (see, e. g., CAMERON, 1981).

Despite an existing penalty some drivers reveal opposite preferences than those stated in (9.5a). For those drivers the expected penalty is not sufficient to induce compliance with the safety measure. Based on rational expectations the compliance can be increased by an increase in the penalty. In this case x_p as well as y_p decrease. This implies a decreasing utility if the penalty has to be paid. Furthermore, the enforcement of the penalty by the policy can be intensified which means that p increases. The penalty $(x - x_p)$ and its enforcement p are substitutes. The higher the penalty the lower the enforcement can be by the police and vice versa.

9.4 Driving Behavior within the Context of Prospect Theory

9.4.1 Expectations in the Absence of a Penalty

Within the concept of prospect theory we investigate changes in asset positions. Let us start with the lotteries in status quo where no penalty exists. As shown in the tables 9.2-9.5, these lotteries are given by $L(0, (1 - r); \Delta y, r)$ (non-compliance/no penalty, case IV) and by $L'(\Delta x', (1 - r); \Delta y', r)$ (compliance/no penalty, case II). Individuals may edit these lotteries as follows:³

1. L contains a zero payoff, which is neglected.
2. The **neutral reference point** is fixed in status quo (L). $\Delta x'$ in L' is **coded** as a loss.
3. If driving belted $\Delta x'$ is realized regardless whether an accident occurs or not. It is **segregated** as a riskless loss.
4. If driving unbelted (L) the loss due to an accident is denoted by Δy . The advantage of the seat belt usage in L' is denoted by $\Delta y' = \Delta y + (\Delta y' - \Delta y)$. Both lotteries, L and L' , share the component Δy . This component is **cancelled**. The remaining component $(\Delta y' - \Delta y)$ in L' is perceived as a gain.

After these editing steps L is interpreted as "keep the status quo". In this lottery the zero payoff as well as the loss in the case of an accident are no longer considered. In turn, L' now consists of $(\Delta x'; (\Delta y' - \Delta y), r)$. Individuals' preferences depend on the further evaluation of L' . They have to evaluate whether there exists a gain or a loss. In the subsequent evaluation phase individuals have to weigh payoffs as well as probabilities.⁴

³ Since the editing steps are not predetermined other results are also conceivable.

⁴ See also figures 9.1 and 9.2.

Table 9.6: Predicted preferences based on prospect theory (no penalty)

preferences	$L \succ L'$	$L \prec L'$
result	driving unbelted	driving belted
motivation	(a) advantages of the seat belt in case of an accident	
	$\pi(\Delta y' - \Delta y) \geq 0$	$\pi(\Delta y' - \Delta y) > 0$
	underweighted	sufficiently weighted
	(b) risk to suffer an accident	
	$\pi(r) \geq 0$	$\pi(r) > 0$
	underweighted	sufficiently weighted
	(c) inconvenience while wearing the belt	
	$\pi(\Delta x') > 0$	$\pi(\Delta x') \geq 0$
	substantial	not substantial
relation	$\pi(r)\pi(\Delta y' - \Delta y) < \pi(\Delta x') $	$\pi(r)\pi(\Delta y' - \Delta y) > \pi(\Delta x') $

1. The loss $\Delta x'$, feeling less comfortable while wearing the belt, is weighed as $\pi(\Delta x')$.
2. The gain $(\Delta y' - \Delta y)$, the advantages of seat belt wearing in the case of an accident, is weighed as $\pi(\Delta y' - \Delta y)$.
3. The risk r , having an accident, is weighed as $\pi(r)$.

Depending on these weights preferences may occur as shown in table 9.6.

$L \prec L'$ (voluntary usage of the belt) is obtained if (a) the advantages of the belt as well as (b) the accident risk are sufficiently weighed. The inconvenience of driving belted should not be substantial. With respect to these results the predictions based on the prospect theory are ambiguous. Both relations of an individuals's preferences may occur if no penalty exists. This result corresponds to the situation in Germany prior to the intensification of the seat belt legislation. As already mentioned, the belt usage rate in those days was less than 50% in urban areas (DIW, 1988, p. 135; DIW, 1993, p. 150).

9.4.2 Expectations in the Presence of a Penalty

If a penalty was introduced (changing context) we have to consider the lotteries $L_p(0, (1-r-p); e, p; \Delta y_p, r)$ (non-compliance/penalty, case III) and $L'_p(\Delta x', (1-r); \Delta y', r)$ (compliance/penalty, case I). Δy_p (case III) also contains the additional penalty in the case of an accident. One additional editing step occurs beside the already mentioned steps in the absence of a penalty.

5. Δy_p is **simplified** by the individual to $\Delta y_p = \Delta y$. The additional penalty in the case of an accident is neglected since it is largely exceeded by the loss due to this accident.⁵

Two lotteries remain:

1. in case of non-compliance (case III): $L_p(e, p)$, the loss of the penalty
2. in case of compliance (case I): $L'_p(\Delta x'; (\Delta y' - \Delta y), r)$, the sure loss $\Delta x'$ of feeling less comfortable and the gain $(\Delta y' - \Delta y, r)$ in case of an accident

The lottery L_p (case III, existing penalty) as well as the above-mentioned lottery L (case IV, no penalty) cover non-compliance with the safety measure. In contrast to L , the lottery L_p no longer refers to "keep the status quo". It is now associated with an explicit loss.

In the subsequent evaluation phase the corresponding payoffs and probabilities have to be weighed. This leads to the same figures ($\pi(\Delta x')$, $\pi(\Delta y' - \Delta y)$, and $\pi(r)$) as stated above. Furthermore, individuals weigh the penalty e as $\pi(e)$ and the probability p as $\pi(p)$.⁶

⁵ In Germany the penalty of DM 40 (now DM 60) is largely exceeded by the average accident costs of at least DM 8,500 (accident with minor material damages, BAST, 2000).

⁶ See also figures 9.1 and 9.2.

Then both lotteries, driving belted and driving unbelted, have to be compared.

$$\pi(\Delta x') + \pi(r)\pi(\Delta y' - \Delta y) \leq \pi(p)\pi(e) \quad (9.6)$$

Driving belted (left hand side of (9.6)) is associated with (a) feeling less comfortable, which is interpreted as a sure loss, and (b) having an accident of less severe consequences, which is interpreted as a gain. Driving unbelted (right hand side of (9.6)) is associated with a loss if the penalty has to be paid. Depending on the associated weights one of the following relations holds:

$$\pi(\Delta x') + \pi(r)\pi(\Delta y' - \Delta y) < \pi(p)\pi(e) \quad (9.7a)$$

$$\pi(\Delta x') + \pi(r)\pi(\Delta y' - \Delta y) > \pi(p)\pi(e) \quad (9.7b)$$

If (9.7a) holds then driving unbelted is always preferred over driving belted. This leads to the revealed preference $L_p \succ L'_p$. If (9.7b) holds then driving belted is preferred over driving unbelted ($L_p \prec L'_p$).

Compared to the lotteries considered in table 9.6, the individual has additionally to evaluate the penalty and its occurrence. Beside the motivations already mentioned in table 9.6 some further motivations arise explaining the preferences in the case of an existing penalty (table 9.7).

Table 9.7: Predicted preferences based on prospect theory (existing penalty)

preferences	$L \succ L'$	$L \prec L'$
result	driving unbelted	driving belted
motivation	(d) amount of the penalty	
	$\pi(e) \geq 0$ underweighted	$\pi(e) > 0$ sufficiently weighted
	(e) occurrence of the penalty	
	$\pi(p) \geq 0$ underweighted	$\pi(p) > 0$ sufficiently weighted

Even if a penalty exists the answer whether compliance or non-compliance with the safety measure is preferred cannot be unambiguously given within the context of prospect theory. Assume that the individual prefers driving unbelted over driving belted prior to the introduction of the penalty. Due to the implementation of the penalty e , the amount of the penalty, as well as p , the risk of having to pay the penalty, may be insufficiently weighed to obtain (9.7b). In this case an individual's preferences do not change. The individual drives unbelted further on. Thus, within this theoretical context it becomes clear why a few drivers still do not use the seat belt even after the introduction of the penalty. Nevertheless, the penalty lowers the preference for driving unbelted. The usage rates of the seat belt consequently increase (see figure 6.4, p. 91).

9.4.3 Concluding remarks

In figure 9.1 the gains and losses of the just considered lotteries are visualized.

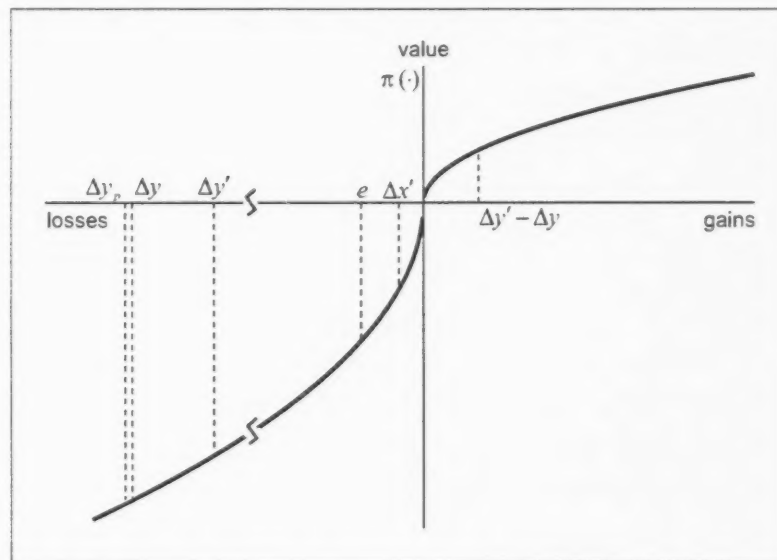


Figure 9.1: Value curvature and driver's behavior, source: according to KAHNEMAN and TVERSKY (1979, p. 279)

1. Δy_p and Δy are close together. Thus, the neglect of the penalty in the case of an accident may become comprehensible.
2. In the case of an accident $\Delta y'_p$ (belted) is substantially smaller than Δy (unbelted). The advantages of the seat belt usage are perceived as a gain $\Delta y'_p - \Delta y$.
3. The penalty e is higher valued than the loss $\Delta x'$. This can be attributed to the unspecific figure of $\Delta x'$, while e is a certain amount of money. This amount of money is perceived as potential out-of-pocket costs. In contrast, $\Delta x'$ is similar to opportunity cost. Even if e and $\Delta x'$ are actually equal, opportunity costs are less valued than the same amount of out-of-pocket costs (THALER, 1980).

Figure 9.2 visualizes the weights of the considered probabilities. Both figures highly depend on the underlying reference point. The accident probability r might be based on the time of exposure (WILDE, 1982a), on the fuel sales (see the empirical analysis in chapter 6.5), or on the distance travelled (EVANS, 1986a; BLUM and GAUDRY, 1999; MOLLETT, 2000). The same holds for the probability p that the penalty has to be paid.

Prospect theory and its extensions by THALER (1980) offer further explanations of how to achieve a higher acceptance of the safety measure. The **regret effect** may bias the decision in favour of compliance with the safety measure. The associated losses of an accident potentially affect an individual's health by causing injuries. Individuals will, therefore, regret any omitted effort which would prevent these losses. Such losses can be clarified by corresponding safety campaigns. Due to these campaigns the losses become highly present in people's mind. Safety campaigns frequently pronounce the consequences of traffic accidents which can be denoted as a **framing** of decisions. Framing also means that the potential negative consequences of seat belt wearing are neglected, such as feeling less comfortable.

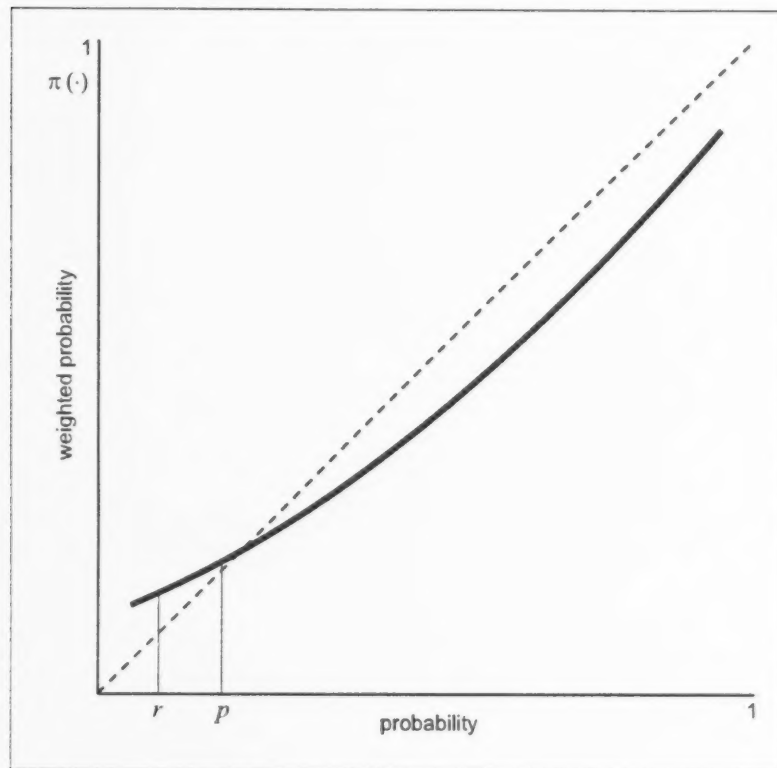


Figure 9.2: Weighting curvature and driver's behavior, source: according to KAHNEMAN and TVERSKY (1979, p. 283)

9.5 Driving Behavior within the Context of Support Theory

Below we analyze the behavioral model in the context of support theory. This theory does not include the valuation of payoffs. It only refers to hypotheses and the judgment of probabilities. In contrast to the other theoretical frameworks we adjust our model in this aspect.

9.5.1 Adjustment of the Model

The set $T_{\mathfrak{A}}$ of the states of the world consists of the events $\mathfrak{A}$ "accident" and $\bar{\mathfrak{A}}$ "no accident". A set $T_{\mathfrak{P}}$ exists containing the events $\mathfrak{P}$ "penalty" and $\bar{\mathfrak{P}}$ "no penalty".⁷ Each of the sets contains two mutually exclusive events, which is denoted by "-".⁸ The assigned **focal hypotheses** are A "individual suffers an accident" and P "individual has to pay a penalty". The **alternative hypotheses** $\bar{A}$ and $\bar{P}$ are given by the negation of A and P . There is $A, \bar{A} \in H_A$ and $P, \bar{P} \in H_P$. Both, H_A and H_P , contain two mutually exclusive hypotheses. With respect to the considered contexts the hypotheses have to be judged as shown in table 9.8.

Table 9.8: Judged hypotheses in different contexts

	context	
	penalty	no penalty
hypotheses	$A, \bar{A}$ $P, \bar{P}$	$A, \bar{A}$

A complete 2×2 matrix is no longer considered. If a penalty exists both sets, H_A and H_P , must be considered. Only H_A is considered in the other context where no penalty exists. Individuals judge the probability of each potential hypothesis. Based on this judgment they then choose their behavior. They can either comply with the safety measure (fasten the seat belt) or they disregard the measure (driving unbelted).

⁷ It is also possible to model all of the events $\mathfrak{A}$, $\bar{\mathfrak{A}}$, $\mathfrak{P}$, and $\bar{\mathfrak{P}}$ in a single set. However, one main feature of support theory is the mutual exclusivity of the events in a set. We, therefore, include only two events in one set.

⁸ Events are usually denoted by " / " in literature (see, e. g., TVERSKY and KOEHLER, 1994). This notation was already used to denote the context "penalty".

9.5.2 Expectations in the Absence of a Penalty

The key feature of support theory is the **unpacking principle**. Hypotheses are presented by a set of **explicit disjunctions**. In the case of traffic accidents these explicit disjunctions of the focal hypothesis "*having an accident*" refer to various accident consequences:

1. light material damages
2. severe material damages
3. light bodily damages
4. severe bodily damages
5. fatality

The categories refer to the official statistics for traffic accidents in Germany (see, e. g., DIW, 1993, pp. 151). The complete set of these categories might not be present in an individual's mind for various reasons. First, the differences between the several categories are arbitrary. For example, the classification of material damages depends on the estimated value of the damages. Second, relevant information might be unknown to the individual. The individual may have in mind the number of fatalities, but it does not know the number of injured victims. In this case the corresponding hypotheses are **not available** in the probability judgments (TVERSKY and KAHNEMAN, 1974). Third, if available, very similar hypotheses might be **repacked** to an **implicit disjunction** (ROTTENSTREICH and TVERSKY, 1997). For example, the individual may have in mind the number of injured victims, but it cannot distinguish between the two types of bodily damages. However, some explicit disjunctions denoted by A_i may remain. The support assigned exceeds the support for the implicit disjunction A "*having an accident*".

$$s(A) < \sum_{i=1}^n s(A_i) \quad (9.8)$$

The probability judgment is given by

$$Q(A, \bar{A}) = \frac{s(A_1 \vee \dots \vee A_n)}{s(A_1 \vee \dots \vee A_n) + s(\bar{A})} \quad (9.9)$$

Depending on the individually judged probability Q two behavioral consequences are conceivable: non-compliance with the safety measure (driving unbelted) or compliance with the safety measure (driving belted). Thus, the predictions based on the support theory are ambiguous.

9.5.3 Expectations in the Presence of a Penalty

In the adjusted model described above we introduced a second set of states of the world T_p . The introduced penalty constitutes a second probability judgment $Q(P, \bar{P})$ in addition to the already existing judgment of $Q(A, \bar{A})$. A sufficiently high probability judgment $Q(P, \bar{P})$ leads to the same consequences as the above-described judgment $Q(A, \bar{A})$. It induces individuals to comply with the safety measure; they then drive belted.

Explicit disjunctions of P are difficult to construct since it is an already unpacked hypothesis. One way to increase the support is to increase the enforcement of the safety measure by the police. The more intensive the enforcement the higher is the actual probability for the hypothesis "*individual has to pay the penalty.*" If this enforcement is accompanied by a corresponding campaign pronouncing police control the individually assigned support $s(P)$ will also increase. If a certain threshold of support $s(P)$ is exceeded the individual will comply with the safety measure.

A certain proportion of drivers might, however, not judge $s(A)$ or $s(P)$ as being sufficiently high such that neither $s(A)$ nor $s(P)$ exceeds their corresponding individual threshold. Depending on the individual probability judgment $Q(P, \bar{P})$ an individual's behavior is not completely predictable in this theoretical context. There also exist a certain proportion of drivers who do not comply with the safety measure.

9.5.4 Concluding remarks

Given the theoretical framework of support theory, it becomes clear which parameter influences the individual probability judgment. The more explicitly the various disjunctions of A are formulated the higher is the judged probability for an accident. i should, therefore, be as large as possible, which means that a wide variety of consequences of an accident should be presented to the individual. Because of the two behavioral consequences an individual threshold must exist where the behavior changes. This means that a sufficiently high support for the focal hypothesis induces individuals to comply with the safety measure. This threshold is, however, unknown. Even a wide variety of explicit disjunctions may not induce all concerned individuals to wear a seat belt. This might be caused by the following two reasons:

1. All explicit disjunctions of A are already presented to the road users. It is, therefore, impossible to obtain a seat belt usage rate above a certain limit.
2. It is too expensive to permanently present all of the explicit disjunctions of A . This means that expensive safety campaigns do not lead to the intended behavior by a sufficient proportion of drivers.

These reasons may induce the legislator to introduce a penalty. This implies a further probability judgment leading to the same two behavioral consequences. Then the probability judgment $Q(P, \bar{P})$ may induce an increasing compliance with the safety measure. If individuals change their behavior after the introduction of the penalty the threshold regarding $s(P)$ is exceeded. They now comply with the measure. Compliance is obtained regardless whether the threshold of $s(A)$ is exceeded or not. Strictly speaking, it is no longer necessary to present all of the explicit disjunctions of A .

Some drivers might comply with the measure because of an existing large i (the threshold of $s(A)$ is exceeded). An additional penalty does not necessarily imply that their threshold of $s(P)$ will be exceeded. If the introduction of the penalty is accompanied by a decrease in i those driver may no longer comply with the

safety measure. This happens if their individually judged support falls short of their threshold of $s(A)$.

9.6 Summary

Above we modelled behavioral decisions in road traffic in light of three theories describing human behavior under uncertainty. The results are summarized in table 9.9. Based on the fundamental principles of the considered theories we can predict individuals' behavior by analyzing the relevant decisional parameters. Some further recommendations can be deduced to improve road traffic safety.

On the one hand, expected utility theory does not distinguish between real payoffs and real probabilities and, on the other hand, their perception by the individual. Based on economic rationality individuals' behavior is not completely predictable. The recommendations found are limited to the case where a penalty is introduced. The other theoretical concepts consider (a) the perception and the valuation of payoffs (prospect theory) as well as (b) the perception and the valuation of probabilities (prospect theory and support theory). The ambiguous expectations within these two theoretical concepts are the result of the individually biased perception and valuation of the decisional parameters. Depending on the result of the evaluation processes individuals might comply with a safety measure or they may disregard it.

Rational expectations combined with individual biases in the decision-making process lead to the following recommendations concerning improvements in traffic safety:

1. If a penalty is introduced we predict safety improvements within any of the three theoretical concepts. These improvements are attributed (a) to the accompanied losses of the penalty and (b) to the enforcement by the police.⁹

2. Even in the absence of a penalty we can deduce some recommendations because of perceptual as well as evaluating biases by the individuals. The safety gains of a measures should be pronounced. Potential consequences of traffic accidents should be present in humans mind.

⁹ Since support theory does not consider payoffs the effects of an increased penalty cannot be predicted.

Chapter 10

Summary and Perspectives

Below the results of the empirical analysis as well as of the theoretical discussion are summarized. We draw some conclusions with particular attention to risk homeostasis theory. The study closes with some suggestions about further research topics.

Empirical Findings

Regarding intensified seat belt legislation we find substantial positive safety effects concerning accident severity. Severe injuries suddenly decrease, while light injuries disproportionally increase. Thus, seat belt wearing prevents severe injuries at the expense of more light injuries. We do not find any additional effect of this safety measure in preventing fatalities in an accident with bodily damages. Furthermore, the accident frequency remains almost constant after the intensification of the seat belt legislation.

After German reunification we find an increase in the accident severity risk compared to the situation which was expected in West Germany without this event. This increase is, however, of only small extent. Severe accident consequences, like fatalities and serious injuries, increases, while minor injuries decreases in an accident with bodily damages. The accident frequency decreases in West Germany

during the 1990s. The situation in East Germany is even more unsatisfying. Accidents with bodily damages are more severe even in the long run. The accident frequency in the eastern part also increases.

Risk Homeostasis Theory

In our analysis of risk homeostasis theory we consider the limited domain of road traffic. We do not find evidence supporting long-term risk adjustment concerning the accident frequency risk as well as the accident severity risk. This holds for both events under consideration, the intensified seat belt legislation and German reunification. Risk substitution due to intensified seat belt legislation also cannot be found. We only find some evidence pointing to risk substitution effects after German reunification.

We have to reject the risk homeostasis thesis in the considered domain of road traffic regarding intensified seat belt legislation. Since our analysis is limited to this domain homeostatic behavior in other travelling modes or even in other domains (WILDE, 1986a;b) might be the focus of some further research. Our finding is this: Offsetting behavior is not observable in road traffic due to intensified seat belt legislation. Non-motivational safety measures, like the installation of seat belts or airbags, can also effectively reduce accident risks in this limited domain.

Human Behavior Under Uncertainty

We find that safety measures generate gains in the seldom event of an accident. These measures are associated with some additional limits in personal freedom in the normal event when no accident occurs. For instance, a speed limit compels the driver to spent more time in road traffic. It is perceived as a sure loss which is very unpleasant. Discussing individual decision-making processes we find empirical data about biases in the perception of the actual accident risk as well as of the gains of a new safety measure. Although these individual biases remain unconsidered in expected utility theory, we can derive some recommendations within

this theoretical context to achieve a higher compliance with a safety measure: The penalty paid for non-compliance with the measure as well as the enforcement by the police should be increased. The investigation of the decision-making processes within prospect theory as well as within support theory provides some further useful contributions. We can derive the following recommendations:

1. Make the gains of a safety measure obvious (perception of gains in case of compliance).
2. Clarify the wide variety of consequences of an accident by explicitly presenting them to the road user (explicit disjunctions for the dangerous event).
3. Remind the road user through the presentation of corresponding statistics that accidents occur at any time and that he is not immune (perception of probabilities).
4. Install an additional loss if the road user does not voluntarily comply with a safety measure (perception of losses in case of non-compliance).
5. Inform the road user about the regular police control if a penalty is introduced (perception of probabilities in case of non-compliance).

In chapter 1 we asked why the car owner did not voluntarily equip his car with an airbag. First, the installation of an airbag was not mandated by law. Thus, individuals did not have to worry about a penalty (WELT, September 21, 1995). This explanation refers to the fourth and fifth points, the perception of additional losses and of their probabilities in case of non-compliance, respectively. Second, in those days the owner may not yet have been aware about the advantages of an airbag for preventing severe accident consequences. This particularly concerns the first point mentioned, the perception of gains in case of compliance. Third, safety campaigns about the present probability (point 3) and the consequences (point 2) of an accident might have been missing. Finally, even if safety campaigns have taken place in those days they may not have been combined with the advantages of the airbag. This device was quite new and was not yet cognitively integrated in decision processes.

All of the above-mentioned points do not affect road users' attitude to risk. The target risk in the homeostatic control loop remains stable (see figure 2.1). Based on risk homeostasis theory we would, therefore, predict no additional safety gains. The five mentioned points, however, change an individual's perceived risk. Our findings show that this change is sufficient to achieve behavioral adaptations by the road users. We can conclude that safety gains in the limited domain of road traffic are also obtainable by changes in the perceived risk.

Perspectives

In the empirical analysis we find that the intensified seat belt legislation does not reduce the number of fatalities in an accident with bodily damages. In this certain case the safety measure reached its limits. This might be attributed to the already high belt usage rates on highways before the penalty was introduced (see figure 6.4). The compliance with the measure is already quite high. A merely marginal increase of compliance is not reflected in a commensurable increase of traffic safety.

Higher risk taking may occur in other domains after the realization of safety gains in road traffic. These potential effects are still unconsidered in our investigation. Like SHANNON (1986), who considers British figures, our empirical analysis of German series finds decreasing overall time trends, e. g., in the number of fatalities per accident with bodily damages. Decreasing trends point to the permanent realization of safety gains in road traffic. These gains might be levelled off in other domains. In order to test the offset of safety gains in road traffic, further research has to consider all of the different risk taking behavior of individuals. For example, data about going bungee jumping has to be integrated. Then a more general risk homeostasis hypothesis can be investigated empirically.

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